ALLOCATION OF CARBON EMISSION QUOTAS FOR SELECTED INDUSTRIES OF THAILAND TO ALLY WITH ECONOMIC EFFICIENCY OF THE MARKET SYSTEM FOR CARBON EMISSION PERMITS

Isaree Jirajariyavech

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ABSTRACT

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Author	Isaree Jirajariyavech
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Thailand Emission Trading Scheme (Thailand ETS) was established to prepare for Thailand's emission trading in playing a part in the global movement for the reduction of CO_2 emissions. The energy intensive sectors, including, petrochemicals, cement, iron and steel, electricity, and aviation industries, are selected to target industries to achieve the reduction of CO_2 emission. The implementation of Thailand ETS can be expected to effect change in the Thailand economy. This study applied the concept of economic cost as the external cost is introduced as a supplement to market allocation of emission quota. The economic cost is computed in terms of the combined strength of forward and backward linkages relevant to industries measured by Leontief's inverse produced by the input-output (I-O) model, using Thailand's 2010 input-output table. The proposed of this study is examine the comparative of two allocation based on the equi-marginal and grandfathering method for carbon emission quotas in Thailand ETS to explore the optimal CO_2 emission quota allocation to ensuring the minimizing the economic cost of allocation.

The Economic Impact – Emission Ratio (EIER) of industries in Thailand ETS is explained by their difference in the magnitude of the economic impact per additional unit of CO_2 emission reduction. The electricity sector was the highest economic impact, followed by iron and steel industries, petrochemical industries, aviation and cement industries. Accordingly, the electricity is much more economic effect for Thailand economy, so the electricity will directly influence on other prices of commodities and services. The EIERs of five targeted industries under Thailand ETS in different vary considerably, for the sake of minimizing the economic cost, it is necessary to explore CO_2 emission quota allocation among the industries according to their EIERs.

The equi-marginal allocation gives all industries in Thailand ETS are equalized economic impact (EI'), therefore the economic efficiency is automatically achieved. In contrast with the grandfathering allocation, EI_j of industries in different vary considerably. The result of the equi-marginal allocation indicated that the electricity sector is the most carbon emission quotas allocation, the quotas of electricity will get the higher than proportion based on historical CO_2 emissions percentage as a reference base year, while the quota allowances for other industries including petrochemical, cement, iron and steel, and aviation are allocated in lower than their proportion.

The optimal allocation of carbon emission quotas in Thailand ETS can be achieved by equi-marginal method, the shares of the computed optimal initial carbon emission quotas for petrochemicals, cement, iron and steel, electricity, and aviation industries are 10.4133%, 10.9711%, 0.7111%, 73.5798% and 4.3247%, respectively. In term of total economic cost of CO_2 quota allocations according to the cap setting 2-5 % CO_2 reduction target, the equi-marginal lower than grandfathering allocation method by 0.017, 0.0383, 0.0681 and 0.1063 respectively. The total economic cost of all industries in Thailand ETS approximately 10.78% can be saved by implementing the optimal emission quotas allocation.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 Statement and Significance of the Study

Global warming caused by increasing of greenhouse gases (GHGs) accumulating in the atmosphere had been a significant global environmental problem. The effects of global warming have led to substantial impacts such as climate change, severe natural disasters including floods, violent storms, and drought, increasing surface global temperature, rising sea levels, ecosystems and biodiversity damage, outbreak of diseases and other public health problems. Thailand is an agricultural country. The livelihoods of most people depend on the abundance of natural resources indicating that climate change is a major threat to food security as well as the economy of Thailand (Office of Natural Resources and Environmental Policy and Planning [ONEP], 2015).

Climate Change 2014: Mitigation of Climate Change of Intergovernmental Panel on Climate Change (IPCC) reported that the overall global greenhouse gas emissions have nearly doubled from 27 Gigatonnes CO_2 equivalent ($GtCO_2e$) in 1970 to 49.5 $GtCO_2e$ in 2010. As shown in Figure 1.1, the proportion of Carbon dioxide (CO_2) emission caused by fossil fuels combustion and industrial processes make up 55% and 65 % of all greenhouse gas emissions, respectively (Intergovernmental Panel on Climate Change [IPCC], 2014).

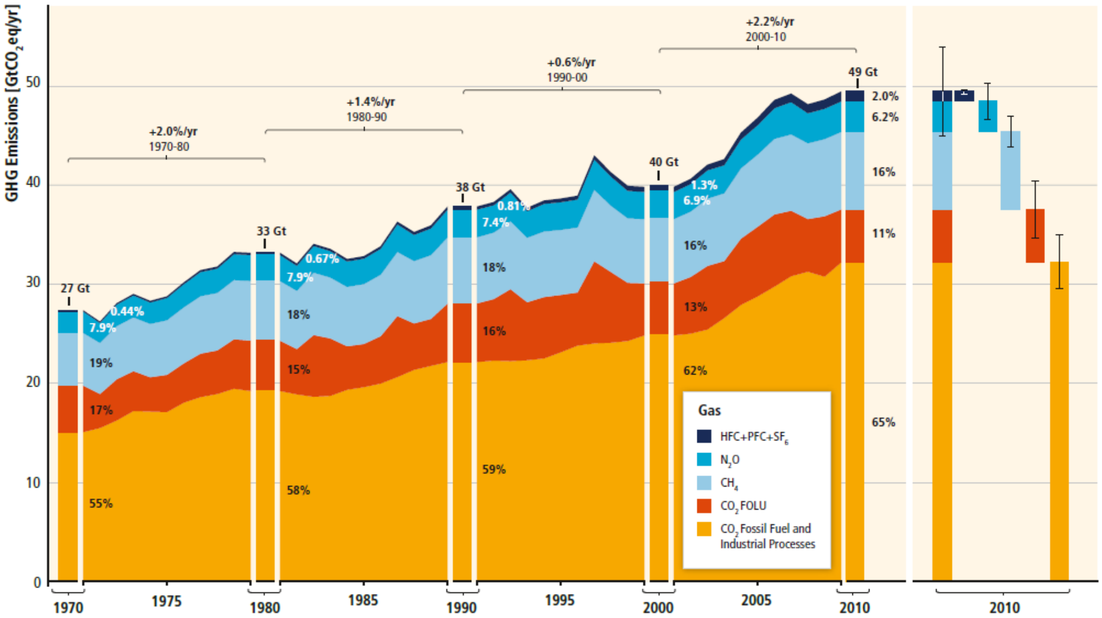


Figure 1.1 Total Annual GHG Emissions by Groups of Gases in 1970 – 2010

Source: IPCC (2014)

The study conducted in Thailand about the amount of GHG emissions during the year 2000-2012 were divided into four sectors: (1) Energy; (2) Industrial process and product use (IPPU); (3) Agriculture, forestry and other land use (AFOLU) and (4) Waste management. The results demonstrated that Thailand's GHG emissions were 350.68 Million tonnes CO_2 equivalent ($MtCO_2e$) in 2012, and it is likely to increase each year at the rate of 5.53%. The energy sector makes up 73.13% of national total GHG emissions. Of the energy sector 256.44 $MtCO_2e$ emissions, fuel combustion to energy industries make up 99.73 $MtCO_2e$ (38.89%), transportation 64.23 $MtCO_2e$ (25.04%), and manufacturing industries and construction 57.68 $MtCO_2e$ (22.49%) (Thailand Greenhouse Gas Management Organization (Public Organization) (Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2015a)

To achieve the target of GHG reduction, international cooperation is required based on the principles of justification and responsibility for different levels depending on the capability of each country (Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2015a). Thailand was signed and ratified as a state party of the Kyoto Protocol. The country is considered as a developing country and is classified as non-Annex 1 with no obligations to reduce GHG emissions. Thailand has implemented Clean Development Mechanism (CDM) and had continuously attended annual conferences about global cooperation to climate change mitigation. In 2014, Thailand's Nationally Appropriate Mitigation Actions (NAMAs) were announced to endeavor on a voluntary basis to reduce GHG emissions in the range of 7–20 % below the Business as Usual (BAU) in the energy and transportation sectors by 2020 (Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2015b). In 2015, The Office of Natural Resources and Environmental Policy and Planning (ONEP) was submitted a letter of intent of Thailand's Intended Nationally Determined Contribution (INDC) to United Nations Framework Convention on Climate Change (UNFCCC). Thailand's objectives were to reduce its GHG emissions by 20% from the BAU level by 2030 (BAU 2030: approximately 555 $MtCO_2e$). The level of contribution could increase up to 25%, depending on sufficient and improved access to technology development and transfer, financial resources and capacity building support under the UNFCCC (Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2015b).

Furthermore, Thailand has recently released a master plan, 'Thailand's Climate Change Master Plan 2015-2050', which is a framework of integrated policies relating to preparedness, adaptation, and climate change mitigation. The plan intends to support climate change preparedness initiatives, reduce GHG emission intensity (emissions per unit of GDP) and apply the appropriate economic mechanisms to reduce GHG which focuses on the carbon taxation and carbon emission trading. The general idea behind this is to enhance the competitiveness and development towards a sufficient economy (Office of Natural Resources and Environmental Policy and Planning [ONEP], 2015) ensuring that the plan is consistent with the twelfth National Economic and Social Development Plan (2017-2021) and contribute to a sustainable low-carbon society.

Thailand Greenhouse Gas Management Organization (TGO) was established by the Thai Cabinet's resolution on May 15, 2007, to function as the public organization under the Ministry of Natural Resources and Environment. The public organization is a government funded autonomous agency. TGO's mission is to play a role of the center for collaboration among government, private sector and international organizations. The objectives are: to organize the market of greenhouse gas quantity trading; and to seek efficiency, as well as to give instructions to public agency and private body in the operations on greenhouse gases.

Thailand Voluntary Emission Trading Scheme (Thailand V-ETS) was established on October 1, 2014 by TGO. The purpose of Thailand V-ETS is the preparation stage toward the emission trading. The preparation involves exchange of information and knowledge among industries. The emission trading is an economic incentive instrument based on the principle of cap and trade. It is widely considered to be the main mechanism for GHG emission reduction tool used by the European Union (EU), the United States of America (USA), New Zealand, Canada, China, Korea, and other countries (International Carbon Action Partnership [ICAP], 2016a; Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2015c). Emission Trading Scheme (ETS) is an effective mechanism to absolutely control the amount of GHG emissions, allowing the flexibility on the part of the polluter to choose the option with the lowest cost, thus minimizing the total costs of reducing GHG (Field & Field, 2006; Kunnoot, 2015a; Zhao S, Shi Y, & J., 2018). Thailand V-ETS focuses on the energy intensive sectors, including the electricity, cement, petrochemicals and iron and steel sectors.

The framework of Thailand V-ETS was designed in preparation for the draft law of emission trading scheme in Thailand by 2020 and may be applied to some industrial sectors. Currently, in the process of the feasibility study and operation testing for measurement, reporting and verification system (MRV). In the preparation stage, participation of Thailand V-ETS is voluntary. At this stage, there is no legal obligation to meet the target of CO_2 emission reduction. Participant commitment is based on agreement and preference. The allocation of carbon emission quota is determined by enterprise willingness to enter agreement. Accordingly, trade of carbon emission quota is not a necessary condition for participating enterprises. For the next stage of Thailand ETS, industries will be obliged to meet the target for GHG emission reduction. The target of GHG reduction is set at 2 % based on the carbon intensity of the reference year (Usapein & Chavalparit, 2017). The GHG emission quota is administered by TGO. The quota is allocated in proportion to existing emission. All parties are definitely given the rights to pollute with fewer quantity than their BAU level. To comply with the regulation, enterprises need to spend to eliminate their excess emission.

Thailand ETS focuses on the highly intensive energy sectors associated with the electricity, cement, petrochemicals and iron and steel sectors. Thailand ETS will increase in production cost of goods and services (Sutummakid, 2011) impacting the relevant macroeconomic factors. The economic study of emissions trading system for Thailand using Dynamic Computable General Equilibrium (CGE) model suggested that GHG reduction cost will increase the production cost of industries, thus weaken the demand and supply of goods and services which further affects employment, income, consumption, production, and real gross domestic product (GDP) (Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2015d). The limitation of GHG emission for participants under Thailand ETS is, as mentioned, that it will lead to product price escalation. The impacts of product price increase will have the different economic effect on their supply chain both backward linkages (upstream sectors) and forward linkages (downstream sectors). Therefore, cap settings and allocation methodologies are required for the consideration of different economic linkages.

In this study, the concept of external cost is introduced as a supplement to market allocation of emission quota. The external cost is economic impact that quantified by the method known as backward and forward linkages measured by Leontief's inverse produced by the input-output system model. The computed allocation of emission quota is used as information for the management of GHG emission quota. The allocation can be optimized on the basis of the equi-marginal principle. The resulting allocation of emission quota is market equilibrium equivalent and is economically efficient.

The objective of the computed emission quota is to minimize total economic cost. In general, external cost can be expected to differ across industries. It is a special case where external cost is same for all industries. In this case, equal percentage of emission quota for all industries will realize minimum total economic cost. In other case where industries differ in external cost, emission quota will differ in percentage to realize minimum total economic cost. The minimum total economic cost is realized by the allocation of overall emission quota for enterprises in any percentage that equates the marginal external cost. This study proposes to examine the cost-effective allocation to explore the optimal CO_2 emission quota allocation among industries in Thailand ETS.

1.2 Objectives of the Study

1.2.1 To compute carbon emission quotas for industries participating in Thailand ETS that minimize aggregate cost of CO_2 reduction.

1.2.2 To compute the total economic impact which is used to represent the economic cost of CO_2 reduction of respective industry.

1.2.3 To quantify saving of economic cost of CO_2 reduction by comparing the equi-marginal with the grandfathering methods.

1.2.4 To offer evidence for the support of CO_2 reduction policies that offer minimum economic cost.

1.3 Scope and Limitations of the Study

1.3.1 Carbon emission quotas introduce constraint in terms of limit or decrease in carbon emission for firms and industries. The presence of this constraint raises cost of emission abatement for firms and industries. Increase in production cost and product price, which is the result of increase in emission abatement cost, weaken demand and economic growth. Thus, it can be viewed that increase in environmental quality is traded off with poor economic performance. The effect of increase in environmental quality is borne not only by firms and industries but also by the entire economy. This study introduces the concept of shadow economic impact as alternative to marginal abatement cost (MAC) of firms and industries, used for the allocation of carbon emission quotas offered by market system. As market or carbon emission quotas exists, MAC of firms and industries is automatically brought to equality. The equi-marginal principle suggests that the sum of cost of firms and industries is minimized, and economic efficiency is achieved.

MAC is narrow in scope as it is internal to firms and industries, and is revealed by reaction to market. The absence of market and thus absence of MAC makes it difficult to offer economic efficiency in managing the allocation of carbon emission quotas. In contrast, economic cost is wide in scope as it encompasses change in welfare of the entire economy. It allows the allocation of carbon emission quotas to take into account net changes to occur in the whole economy. The difference of the resulting allocation is the accounting of changes in the whole economy. The allocation of carbon emission quotas is, thus, managed by public policy rather than by market alone.

To manage the allocation of carbon emission quotas that is based on the principle of economic efficiency, the managed allocation needs to be compatible with market allocation. A general idea is to equate external costs of industries known as equi-marginal principle. In principle, economic efficiency is automatically achieved by equi-marginal cost as the result of market system. In this context, market automatically brings cost of firms and industries to equality. The sum of cost of all firms and industries is minimized as marginal cost is brought to equality.

The same principle applies to managed allocation of carbon emission quotas. External cost is brought to equality based on computed allocation. Public policy plays a role similar to market. The shortcoming of this method is that the computed allocation needs to update manually. In contrast, market automatically update the allocation.

1.3.2 To apply economic impact as external cost in the allocation of carbon emission quotas, economic impact is computed in terms of the sum of forward and backward linkages relevant to industries based on input-output table. Economic impact is assumed to be inversely in linear association with the amount of emission as computed from data for fossil fuel consumption. Consequently, decrease in emission raises economic impact as shown in Figure 1-2. Economic impact is measured on vertical axis while emission is measured on horizontal axis.

The difference in the value of forward (customer chain) and backward linkages (supplier chain) for each industry results in difference in value of economic impact. Likewise, difference in intensity of fossil fuel use for each industry results in difference in magnitude of carbon emission.

As country emission quota is applied, firms and industries are obliged to reduce emission in proportion with overall quota. The quota that requires reduction in emission raises cost of production, product price, weakens demand, and compromises economic performance. The extent of economic impacts depends on the structure of forward and backward linkages. As Figure 1-2 show, cleaner environment is traded off with greater economic cost. The task facing policy management is to achieve cleaner environment with minimum cost.

As economic impact differs among firms and industries, the allocation of carbon emission quotas in proportion with overall quota is not necessarily at minimum cost. It is only when economic impact for all firms and industries is equalized, that total economic cost is at minimum. With this principle, the allocation of carbon emission quotas can be managed to equate economic impact to ensure minimum economic cost.

1.3.3 The Leontief (Leontief 1936) Input-Output model is devised to evaluate the backward linkages and forward linkages based on the input-output table of Thailand for 2010 released by Office of the National Economics and Social Development Board (NESDB). The backward linkages and forward linkages were evaluated based on 180 sectors input-output table. As the input-output table can be updated with five years interval, careful interpretations are needed as this study assumes that the time distance over the period between the release of the input-output table and the present has not changed Thailand economic structure.

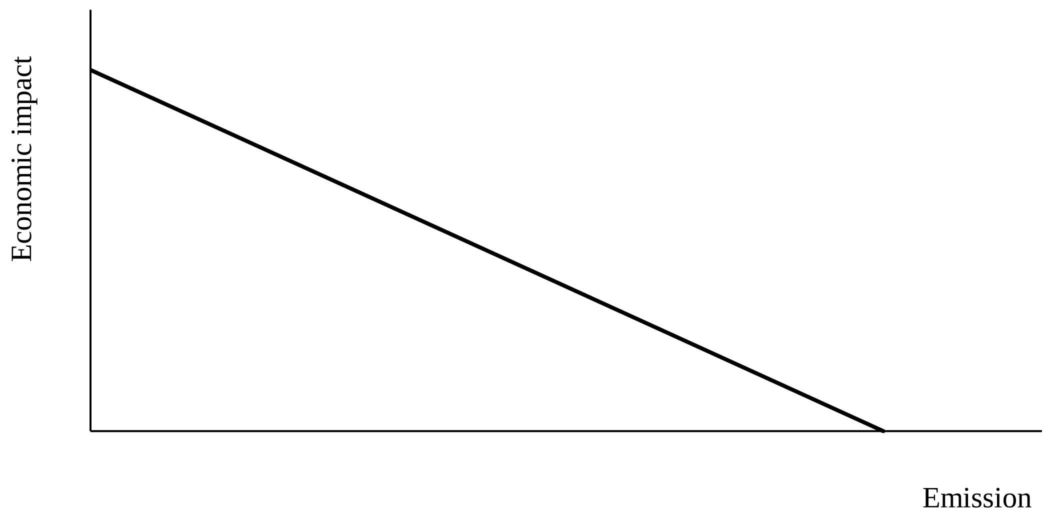


Figure 1.2 Economic Impact for Single Industry

1.3.4 As the allocation of carbon emission quotas is concerned with officially selected target industries, the amount of CO_2 emission is calculated as direct for particular industries that are targeted to participate in Thailand ETS. Fossil fuels are scoped in this study to comprise coal and its products (anthracite, bituminous, lignite, coke, briquettes and other coal), petroleum products (diesel, gasoline, fuel oil, kerosene, jet fuel, and liquid petroleum gas), and natural gas. The data for industry fossil fuels consumption are drawn from the input-output table for year 2010. Coal and lignite are shown in sector 030, petroleum refineries in sector 093, and gas in sector 136. The amount of CO_2 emission is computed from the 2010 input-output table. The value of fossil fuel consumption is converted into quantity of oil equivalent fossil fuel which is converted into quantity of CO_2. The conversion is based on the fuel prices reported in Thailand energy situation in 2010 and Energy balance of Thailand in 2010.

1.3.5 The general criteria for targeted participants under Thailand ETS is energy intensive industries consumption and significance of the amount of GHG emissions. The sectors chosen as participants in Thailand ETS are petrochemical production, cement production, Iron and Steel production, electricity, and aviation, which are classified as sectors 086; 102; 106; 135; 156 in the input-output table respectively. Given that a fixed GHG emission reduction target 2-5% based on the reference year by implementation under Thailand ETS administration.

1.4 Definitions

CO_2 emission is the direct CO_2 emissions from fossil fuels combustion which is calculated by emission factor following the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Intergovernmental Panel on Climate Change [IPCC], 2006). The amount of CO_2 emissions is computed in term of CO_2 equivalent (CO_2e)

Economic impact is the magnitude of economic linkage that are summed over the supply chain and customer chain throughout the economy. The economic impact is the sum of backward linkages and forward linkages, which are computed in terms of the Leontief inverse after the evaluation of the input-output model equation.

The equi-marginal is the method of the managed allocation is market equilibrium equivalent. At equilibrium, market establishes a price which equals marginal cost of all enterprises, thereby bringing demand and supply to equality. The market equilibrium is a condition to realize efficiency, wherein cost is at minimum and profit is maximized. As the principle of equi-marginal cost is applied, the allocation of emission quota becomes non-proportional to existing amount of emission. Industry with high cost will be required to reduce less GHG emission, whereas industry with low cost will be required to reduce more GHG emission. The sum of cost of GHG emission reduction of all industries can be proved to be at minimum.

1.5 Expected Benefits of the Study

The finding of this study provides policy analysis for carbon emission management seeking cleaner environment with minimum economic cost. In absence of market, managed allocation of carbon emission quotas based on equi-marginal principle provides channel for policy makers to gain economic efficiency in achieving environmental target in similar manner as market offers. Computed economic cost provides wider perspective accounting of impacts for the entire economy. Policy makers are better informed for available alternatives in environmental management.

CHAPTER 2

LITERATURE REVIEW

Emission Trading Scheme (ETS) is a market-based mechanism to encourage GHG emissions mitigation which has become one of the most important instruments to achieve the targets of climate change mitigations. ETS is highly flexible tool that applies Equi-marginal principle to accomplish the goals of GHG reduction and consequently minimize the aggregate national cost (Kunnoot, 2015a). However, certain limitations exist for productions and services of sectors that are likely to participate in Thailand V-ETS in that economic linkages will be affected. In other words, one change in the sector could affect and impact other sectors. This section will explain and clarify the mechanism of ETS, principle of allocation carbon quota permits, the situation of ETS, and economic impact of ETS.

2.1 Principle of Emission Trading Scheme

Emission trading scheme (ETS) works on the principle of cap and trade where the government determines a limit of the total GHG emissions (Cap) in one or more sectors of the system and then allocate the quota of emission permits to each participant. ETS provides great flexibility for individual participants to decide how to best meet their obligations. The participant can reduce their own releases and/or buy surplus permits from other participants. On the other hand, if a participant emits less than their allocated allowance, they may “bank” the remaining allowances for the next year or sell them to other participants (International Carbon Action Partnership [ICAP], 2015a, 2016a; Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2015c) as shown in Figure 2.1. These individual choices mean that the costs of participants staying under the ETS are minimized thus achieving GHG emissions targets and lowering the social cost for GHG reduction.

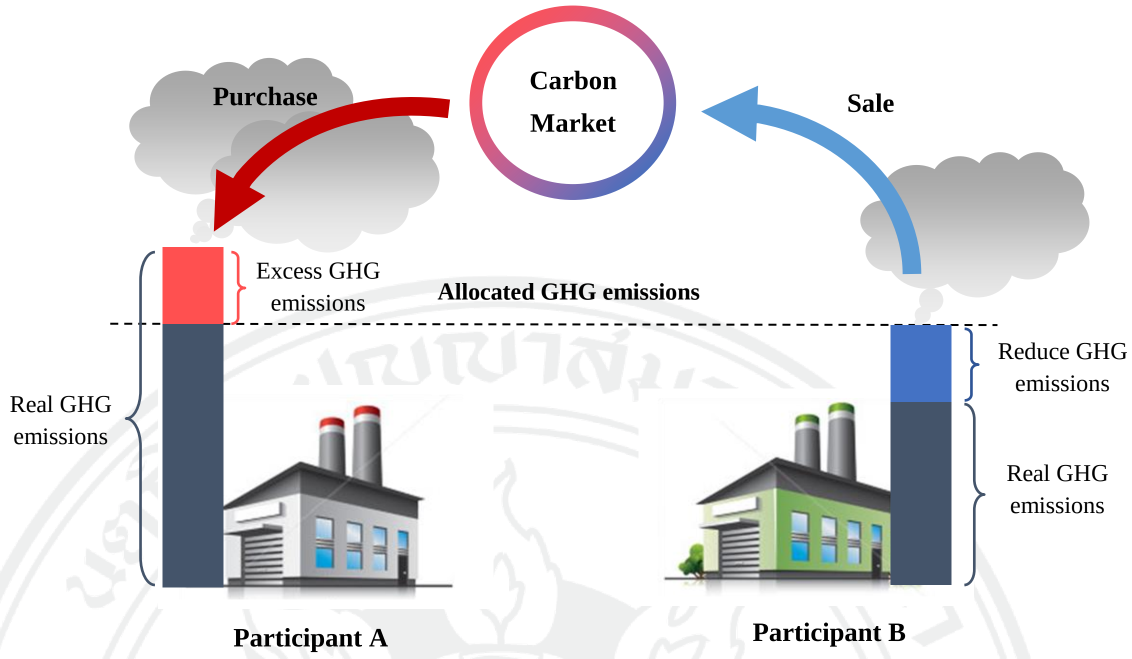


Figure 2.1 Concept of Carbon Emission Trading Scheme

ETS is considered to be a cost-effective method to achieve GHG emissions reduction target through the use of flexibility mechanisms rather than compulsory regulations (C. Zhang, Wang, Shi, Li, & Cai, 2016). In terms of the economic incentives associated with GHG reduction, ETS has been proven to be more effective than carbon taxation after the initial stage (Stern, 2008). However, it is important to note that ETS and carbon taxation have different advantages and disadvantages. Policy selection can select based on the reduction target and national characteristics. At the initial stage of GHG reduction, carbon taxation is efficient because of its lower implementation cost. ETS can then be applied as it is well defined towards the overall GHG emission and it has the potential link to international carbon markets (Keohane, 2009). (Marshall, 1998) suggested that small enterprises and residents prefer the use of carbon tax for consuming fossil fuels, while the large businesses or high GHG emission participates in ETS.

2.1.1 Mechanism of Emission Trading

Marginal abatement cost (MAC) is the costs for emission reduction by the polluter into the environment and generally differs depending on various factors such as location, manufacturing, production capacity, type of fuels, pollution reduction technology, time, and other factors. Even for same type of emission, it is possible to have different MAC. Figure 2.2 displays a general MAC curve where the horizontal axis shows the quantity of pollution emission with emissions increasing from left to right. The maximum emission level (E_{max}) is the amount of emission with no control.

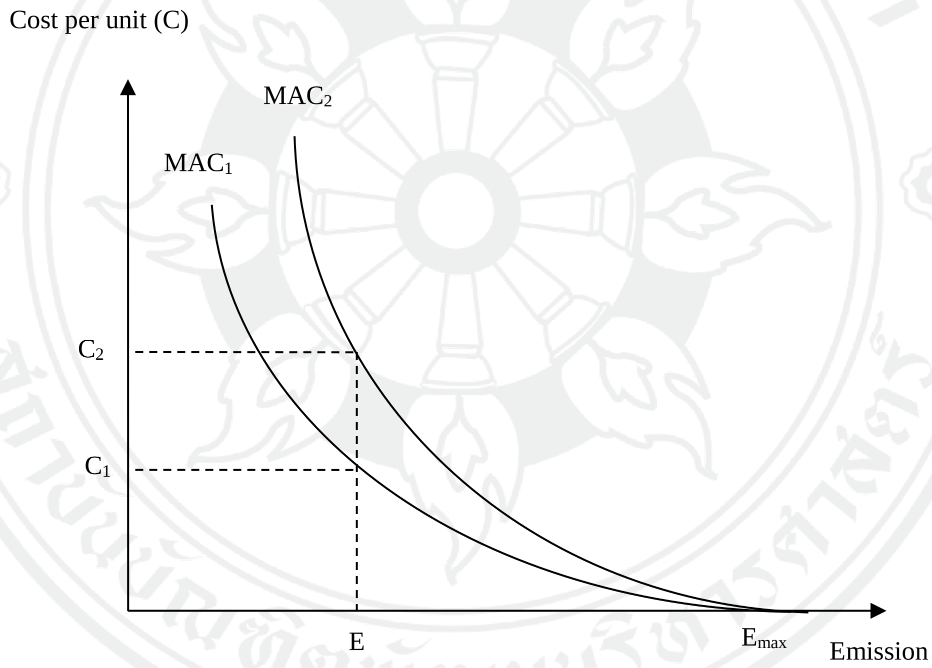


Figure 2.2 The Marginal Abatement Cost Curves
Source: Field and Field (2006)

Trade of emission quotas is motivated by profit. If marginal abatement cost (MAC) of enterprises differs, all parties will be automatically divided into the buying side for those with higher MAC than the asking price of the rights to pollute, and the selling side for those with lower MAC than the asking price of the rights to pollute. The rights to pollute will be redistributed between the supply and the demand sides. Price of the rights to pollute adjusts until equilibrium is established where the difference of demand and supply is completely eliminated. At equilibrium, MACs of all enterprises are equal to price of the rights to pollute. Accordingly, total efficiency is achieved as the sum of abatement cost of all parties is at minimum. In this context, the quota of emission is distributed by market. However, in a circumstance where the difference of MAC does not exist, trade will not occur, and initial allocation of emission quota remains unchanged.

As ETS policy is implemented, individual polluter will lower the emission to below E_{max}, hence the shift from right to left on the horizontal axis. MAC curves illustrate the marginal costs of emissions reduction indicating that MAC curves rise from right to left. During the initial phase, the decrease in emission might be obtained through the gradually rising MAC. Subsequently, to further reduce the emission, new investment in technology is required resulting in significant increase in MAC (Field & Field, 2006). The total cost of individual polluters is area under the MAC curve between E and E_{max}. The aggregate MAC curve is a summation of individual polluter. Polluters will desire to reduce emission from E_{max} to E level. The MAC will depend on the total emissions allowed among the different sources. The different MAC of polluter is an important condition of the ETS implementation to achieve the emission reduction target (Sutummakid, 2011).

As illustrated in Figure 2.3, MAC_1 and MAC_2 ($MAC_1 < MAC_2$) are the marginal abatement cost of GHG reduction for participants 1 and 2, where emission permits Q_1 and Q_2 are allocated to each participant without ETS. A and B are the costs of C_1 and C_2 ($C_1 < C_2$) for participants 1 and 2, respectively. In contrast, when ETS is allowed, the carbon market will be generated, and the participants will adjust their buying and selling according to their MAC. Participant 1 (lower MAC) tend to sell emission permits ΔQ_1 to the market, whereas participant 2 (higher MAC) tend to buy emission permits ΔQ_2 from the market. New equilibrium point at A′ and B′ is established and the MAC of participants 1 and 2 are identical at the cost of C′ (Wu et al., 2016).

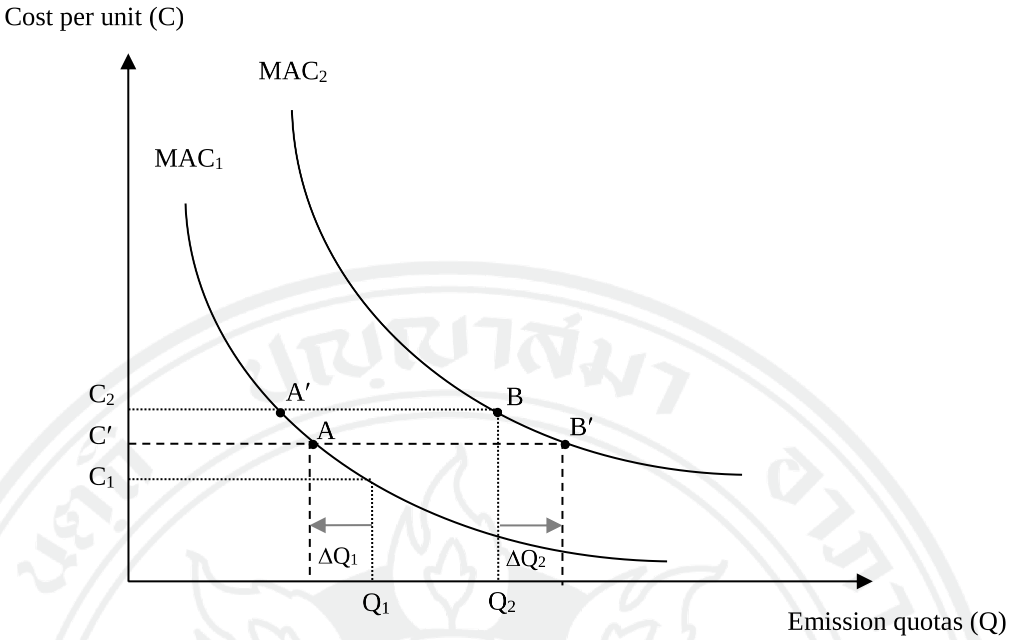


Figure 2.3 Emission Trading Mechanism between Different Sectors.
Source: Wu et al. (2016)

In ETS, the government sets the maximum amount of GHG emissions allowed. The cap must be set at a lower than the business as usual (BAU) level of emissions to ensure the scarcity of market. The participants that encounter higher marginal abatement cost (MAC) than the market permit price can buy additional permits, whereas the participants who encounter lower MAC can sell their emission permits for a benefit, thus providing GHG reduction incentives. In theory, the ETS mechanism can achieve the target for minimizing the overall cost of GHGs reduction (Cui, Fan, Zhu, & Bi, 2014; F. J. Li, Zhang, Wang, & Cai, 2012).

The mechanisms of ETS are explained in equation (1) and (2).

Amount of emission permits selling equal to buying:

$$\Delta Q_1 = \Delta Q_2 \quad (1)$$

Expenditure of buyers equal to revenue of sellers:

$$\Delta Q_1 C' = \Delta Q_2 C' \quad (2)$$

The total emission permits of all buyers and sellers in the market are shown in Equation (3) and (4).

$$\Sigma\Delta Q_s = \Sigma\Delta Q_b \quad (3)$$

$$\Sigma\Delta Q_s C' = \Sigma\Delta Q_b C' \quad (4)$$

where

s is seller in the carbon market

b is buyer in the carbon market

ΔQ is emission permits trading volume

C is cost of GHG reduction

The ETS mechanism provided to the MAC of participants are equal, therefore, accomplishing the condition of equi-marginal principle (Richard, William, & Daniel, 2012). The individual participants can decide how to implement strategies to ensure the lowest cost, and as a result, the total national cost for GHG reduction is minimized, thus achieving economic efficiency.

In addition, several studies investigated that ETS can bring about higher economic efficiency compared to other mechanisms. Stern (2008) compared the efficiency and incentive effects of ETS and carbon taxation and indicated that ETS has lower cost and is more effective in terms of GHG reduction incentives. Moreover, Cui et al. (2014) conducted a study on the cost-saving of ETS in China and found that the government intentions to achieve the reduction in carbon intensity (carbon emissions per unit of GDP), unified ETS is required as it has the lowest total abatement costs resulting in different cost-saving effects for different provinces and different MAC.

2.1.2 The Equi-marginal Principle Applied to Emission Trading

The difference of the marginal abatement cost (MAC) facing respective firms induces trade of emission rights. Firms having high MAC increase saving by extra emission rights as far as they cost less than their own MAC. On the other hand, firms having low MAC increase profit by offering extra emission rights as far as they earn more than their own MAC. At equilibrium, where trading price equates demand and supply of emission rights, MACs of all firms are equal, and the abatement cost of all firms sum to the minimum. This is known as equi-marginal principle (Berck & Helfand, 2011; Field & Field, 2006).

The ETS mechanism is especially relevant in the equi-marginal principle when there are several GHG emission sources with different MAC and they are desires to reduce GHG emissions under the quota of emission permits at the minimum possible cost. Different MAC will allow trading among polluters and push the system into new equilibrium point where the demand and supply are equal. In Figure 2.3, all emissions from the various sources have the same MAC which is in accordance with the equi-marginal principle of the trading equilibrium. The emission reduction target is achieved at the minimum total cost. Firms will benefit by selling allowances whenever the permits price is higher than MAC or saving control cost by purchasing permits whenever the permits price is below MAC.

Additionally, the equi-marginal principle can be applied for achieving the GHG emissions target at the minimum aggregate national cost. The government regulator could set the emission permits for low MAC polluters less than its percentage allocation or they will do the majority of the emission abatement. On the other hand, the polluters who have higher MAC should be allowed to emit more than the proportional of existing emissions or they will do a smaller amount of emission abatement (Abrell, Rausch, & Yonezawa, 2016; Jaccard, Nyboer, & Sadownik, 2002; Meyer, 2015). Consequently, individual sources should increase or decrease its emission reduction efforts until the incremental costs for the next reduction unit are equal. The total national costs saving can be calculated by estimating the total cost of polluters achievements at the same percentage emission reduction and compare it with the total costs of sources that are allocated according to the equi-marginal principle (Jaccard et al., 2002). The minimum aggregate cost of emission abatement contributes to the economic efficiency perspective and is considered to be the most important ETS policy for GHG emissions control.

2.1.3 The Cap Setting in Emission Trading

To set a cap on ETS, the historical GHG emissions, forecasts the GHG emissions rate and assessment of GHG reduction potential is required. Different GHG reduction target have significant economic impacts, so the purpose and possible factors must be clarified for each sector under ETS. Government estimates GHG emissions for a period of time and then define the overall cap lower than that level. The excessive emission limits would produce no price signal and no trading. Inadequate cap setting would increase the carbon price and have a negative impact on the economy. The ETS regulator should be carefully with the cap setting and total allowances in the carbon market to ensure balance and mitigation effect (Tang, Wu, Yu, & Bao, 2017). There are two types of emission caps: (1) Absolute target and (2) Intensity target, as shown in Table 2.1.

Table 2.1 The Different of Cap Setting on Emission Trading

Description	**Type of GHG cap setting**	
	Absolute target	**Intensity target**
GHG emissions target	- GHG emissions expressed in term of tonnes CO_2 equivalent (tCO_2e)	- GHG emissions expressed in term of tonnes CO_2 equivalent per unit of output (tCO_2e/ output unit)
Advantages	- Assuring for maximum GHG emissions quantity - Identification of the amount of GHG reduction per year, allowing for better management and control strategies - Provide an effective system as the market scarcity cause the emission permits demand	- Flexible mechanism according to the output growth, GHG emission is linked to future GDP and automatic emission allows.
Disadvantages	- It is not flexible; the recession automatically reduced the output for GHG emissions as there are many uncertainties in the economy and trade prohibition	- Difficult to manage if the absolute quantities of GHG reduction per year are unknown. -Requires reports and verifications of output increases for each year

Source: Thailand Greenhouse Gas Management Organization (Public Organization) [TGO] (2015c)

2.1.4 Emission Permits Allocation

The allowances (or emission permits) refer to the quota of GHG emissions distributed to individual participants in the system during a period of time. The different emissions allocation approaches can be classified into two groups, namely free allocations and auction approaches.

2.1.4.1 Free Allocations

As the most generally approach, it refers to emission permits that are allocated free of charge. This approach encourages firms to reduce GHG emissions by operating gently at first before gradually changing to other distribution, such as auctioning (Jegou & Rubini, 2011). There are three principal methods for determining free allocations: grandfathering, output-based allocation and benchmarking.

1) Grandfathering

Grandfathering (GF) or fixed allocation is allocated for free emission permits in proportion based on the historical GHG emissions percentage as a reference base year (Böhringer & Lange, 2005; Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2015c; Zhou & Wang, 2016). This approach can be easily implemented and is commonly used during initial start-up phases of ETS (F. J. Li et al., 2012; L. Liu, Chen, Zhao, & Zhao, 2015; H. Wang, 2016). Many firms prefer to use this approach to minimize impact of the business competitiveness (F. J. Li et al., 2012), satisfaction levels and is the potential for decreasing the carbon leakage in terms of related emission increase outside the country (Schmidt & Heitzig, 2014). However, the disadvantage of grandfathering is that it may reduce the motivation of individual participants because there are expectations that the allowances will increase based on possible emissions in the future (Jegou & Rubini, 2011).

2) Output-based Allocation

In Output-based allocation (OBA), the emission permits are distributed based on the output shares of individual participants, in other words the allocation allowances among sectors are defined by proportion of baseline emissions share (The Organisation for Economic Co-operation and Development [OECD], 2010). This method refers to GHG emissions per unit of physical output product and the allocation to individual participants based on their output share within the sector. Although OBA increases the firm's costs, the increased pricing of goods is lower than grandfathering and auctions methods (Takeda, Arimura, Tamechika, Fischer, & Fox, 2011). An allocation of CO_2 emission permits based on economic outputs is considered more reasonable than grandfathering method (Zhao, Min, Geng, & He, 2017).

3) Benchmarking

Benchmarking (BM) method avoids the negative impact from grandfathering by distributing emission permits based on performance standard or benchmarking the most efficiency emission implementation. Free total allowance are dispensed to participants who emit less than benchmark while the participants who emit more than benchmark are required to purchase emission permits and must make efforts to reduce GHG emissions to reach the benchmark (Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2015c). Benchmarking method creates an incentive for participants to reduce emissions and guarantee non-distorted carbon price signal (Jegou & Rubini, 2011).

Allocation methods through free permits, benchmarking and grandfathering are considered the most general principles (Tang, Shi, & Bao, 2016).

2.1.4.2 Auctioning

Auctioning (AUC) method creates price mechanism and represents the real costs of GHG reduction. Under a standard auction, the government collects the revenue that is used for recycling, for reducing the negative economic effects on the businesses, and for investments in low GHG emission technologies to accomplish the cap target (Burtraw, Palmer, & Kahn, 2005; Peskoe, 2016; Yuan, Shi, Li, & Zhou, 2012). Several studies suggested the auctioning method as a way to achieve lowest cost of overall GHG reduction on the national level (Hübler, Voigt, & Löschel, 2014; Munnings, Morgenstern, Wang, & Liu, 2016; Tang et al., 2016). However, a major disadvantage to this methodology is the decrease of competitiveness of international trade among the high energy consumption sectors (Takeda et al., 2011).

Relevant previous studies focused on the effect of different emissions permit allocation of ETS mechanism. The different permit allocation methods in the United States and found that combining auctioning and output-based allocation for energy intensive sectors could be more effective than auctioning alone (Fischer & Fox, 2010). Similarly, Takeda et al. (2011) compared the effects of auction, grandfathering, and output-based allocation in the Japanese ETS by taking into account three factors–macroeconomic impact, carbon leakage and competitiveness and explained in the results that the combination of auctions and output-based allocation are desirable.

With the focus on the grandfathering and output-based allocation, the impact of different allowances allocation of ETS on China's power sector and found that grandfathering might lead to both higher electricity and carbon prices than output-based allocation (Cong & Wei, 2010). Therefore, output-based allocation would be more contributing to the reduction of GHG emissions in the Chinese power sector and encourages participants under ETS to be more environment friendly. Böhringer and Lange (2005) studied grandfathering and output-based allocations and pointed out that in a closed trading system, effective allocation requires the use grandfathering. In open trading system, however, effective allocation is usually based on a combination of grandfathering and output-based allocations. The impact between different free quota ratio of grandfathering and suggested that the proportion of free quota should be gradually reduced in ETS to prevent violent fluctuation of carbon price (W. Li & Jia, 2016).

Regarding allocation between free permits and full auctioning of carbon allowances, Hübler et al. (2014) indicated that free allocation and auctioning result in similar macroeconomic effects, but full auctioning leads to higher losses in output as compared to free allocation for sectors under ETS. Recycling revenues from auctioning could be returned to business and invested in energy efficiency improvement by government. An auction is more feasible than grandfathering for free allocation because it is more efficient and provide greater incentives for the adoption of low-carbon technologies (Cramton & Kerr, 2002). The government gets the scarcity permits and the auction revenues could be used to reduce economic impact. Similarly, Tang et al. (2016) examined the impacts of various ETS policy designs in China and found that subsidy from auctioning revenue are strongly recommended in the initial stages of ETS to avoid significant economic loss and the carbon cap should be carefully designed to balance the economic impact and GHG reduction.

2.1.5 Economic and Environmental Impacts of Carbon Emission Trading

Carbon ETS is closely related to economic units: firm, household, and the government. Increase in cost of production effects to the products price. As the product price increase, the demand and supply of goods and services will decrease. Carbon ETS will result in various economic and environmental effects, for instance, real GDP, employment, investment, consumption, import, export, sector's outputs and other indicators, consequently resulting in economic growth slowdown (Y. Liu, Tan, Yu, & Qi, 2016; P. Wang, Dai, Ren, Zhao, & Masui, 2015; Wu et al., 2016). Previous studies have examined the influence of carbon ETS on the economy by evaluating the effects of a carbon pricing which can be divided into two categories: Computable General Equilibrium (CGE) analysis and Input–Output (I–O) analysis.

CGE model has been used by a number of studies to assess the economic impacts of carbon ETS policy in different countries. The European Union's emission trading scheme (EU ETS) is the largest carbon market and its effects are estimated continually. The effect of the EU ETS on economic growth of the EU countries during period year 2003 to year 2012 and found that the EU ETS have negative effect on economic growth (Oberndorfer, Rennings, & Sahin, 2006). Industrial outputs decrease because of the rise of goods price which impacts the upstream and downstream industries leading to abated competitive ability of commodities from other countries. The macroeconomic effects of third EU ETS period 2013–2020 and noted that the GDP of EU would reduce by 1.3% by 2020, exports would reduce by 1.8%, domestic demand would reduce 1.2%, industrial production reduce by 1.5%, and unit costs in industry would increase by 2.1%. These changes were caused by higher electricity prices leading to rising industrial production costs (Rantala, 2012). The economic growth will depend on the allocation of free emission permits in electricity production, a critical issue for economic developments in the EU countries. Thus, the EU climate policies emphasize on nuclear power and renewable energy for non GHG emission from electricity generation.

In China, seven pilot ETSs were established in two provinces (Hubei and Guangdong) and five cities (Beijing, Shanghai, Shenzhen, Tianjin and Chongqing) in 2010 to achieve the target of Intended Nationally Determined Contributions (INDC) by 2030 in a cost-effective way. The target was set to reduce carbon intensity by 40–45% from the 2005 levels by 2020. Study to assess the economic impacts of ETSs in China include estimates of the economic impacts of carbon ETS in China (F. J. Li, Wang, Zhang X. Y., & Kou, 2014). This study found that ETS could be effective in reducing CO_2 emissions. However, it may have negative impact for macroeconomic growth of the country. Total CO_2 emissions reduction ranges from 6.8% to 11.2% and the short-term negative economic impacts of the carbon price of 100 RMB/tCO_2 are as follows: GDP reduced by 1.1% in 2007, investment reduced by 1.52%, employment decreased by 0.67%, domestic price increased by 0.22%, exports decrease by 0.64% and consumption decreases by 1.13%. As per their goal, China was required to reduce CO_2 intensity in 2020 to 45% below 2005 level with carbon ETS inducing to GDP loss of approximately 1.2%, decline of Chinese export by 3%, indicating that ETS policy could cause domestic goods to be more expensive than import goods (Hübler et al., 2014). The economic impacts of local pilot ETSs in China have been widely investigated. Liu et al. (2016) simulated the economic impact of Hubei pilot ETS by applying CGE model and found that

Hubei pilot ETS had significantly reduced CO_2 emission with its contrast impact on economy. In 2014, the CO_2 emission was reduced by 1.00%, the provincial GDP decreased by 0.06% (1.48 billion Yuan), the employment and investment rate decreased by 0.09% and 0.33%, respectively. In terms of international trade, exports and imports declined slightly by 0.07% and 0.11%. Similarly, Wang et al. (2015) analyzed the economic impacts of carbon ETS in Guangdong province and found that ETS is closely related to economic impacts as carbon intensity is estimated to be reduced by 34% by 2020, GDP reduction was 0.9%, export by 2.2%, import by 1.4% and government expenditure by 1.2%. The results imply that more stringent carbon reduction target must be set forth to ensure lowest possible economic loss. Additionally, high carbon trading prices may have negative effects on the economy in terms of trade competitiveness and household consumptions (Mo, Agnolucci, Jiang, & Fan, 2016). Likewise, Wu et al. (2016) assessed the economic impacts of ETS policy in Shanghai and explained that ETS could reduce CO_2 emission by 1.1%-1.3%, induce GDP loss by 2.2%-2.3% by 2030, and international trade and interprovincial trade would decrease by 1-4%. Different loss rates and decrease in output will occur to ETS participating sectors. Iron & steel sector suffered the most loss (20.4%), followed by electricity sector (15.6%) and oil refinery sector (13.7%). All the studies indicate that policy regulators must carefully design the cap and allocation permits as this is the key of controlling carbon prices and trading volumes in the market.

The short-term effects of carbon mitigation policies on the Japanese economy using Input–Output (I–O) model and observed that the carbon pricing could result in dramatic cost increase on industrial sector and create loss for Japanese exports (Sugino, Arimura, & Morgenstern, 2013). For that reason, free allocation should be based on the cost structure. The target industrial sector with high direct costs from fossil fuel combustion such as the iron and steel, chemical, and paper and pulp sectors should consider free allocations following implementation of ETS. Many studies explored the impact of ETSs in other countries, i.e. Britain (Edwards & Hutton, 2001), Spain (Labandeira, Linares, & Rodriguez, 2009), Germany (Graichen, Matthes, & Schumacher, 2016) and other countries and suggested similar findings.

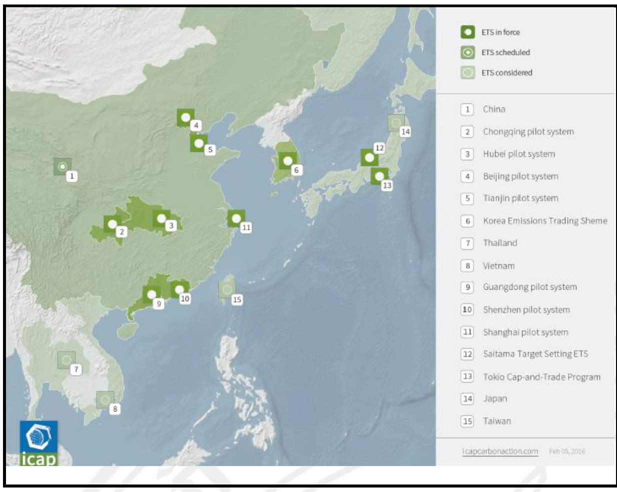
Although, the carbon ETS contributed negative impact on economy, it could lead to positive effects on the environment. Some studies focused on the co-benefits of carbon ETS policy on reducing air pollutants. The impacts of ETS on air pollutant reduction in Guangdong province and found that by 2020, Guangdong pilot ETS has the co-benefits of reducing SO_2 and NO_x emissions by 12.4% and 11.7%, respectively as compared to the BaU (Cheng, Dai, Wang, Zhao, & Masui, 2015). Similarly, Jiang et al. (2013) analyzed the co-benefits of GHG mitigation and noted that the GHG emissions reductions contributed to the decrease in other air pollutants such as SO_2, NO_x, CO and particulate matter (PM), which in turn, could solve the local environmental problems and improving public health.

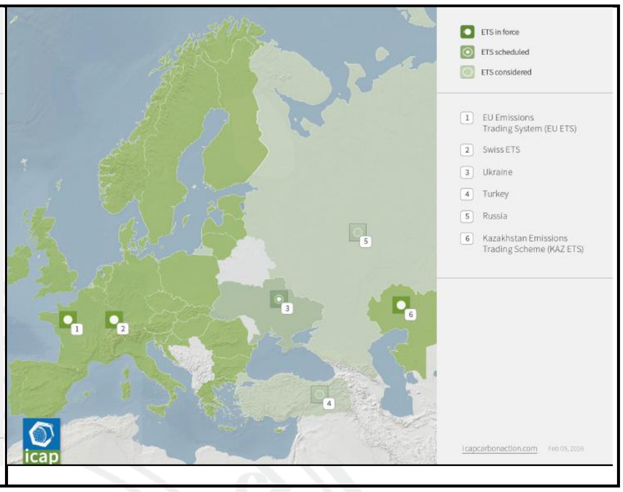
2.2 Statement of the Carbon Emission Trading Systems

2.2.1 The Global Carbon Emission Trading Market

The International Carbon Action Partnership (ICAP) Status Report 2016 illustrated the success of carbon emissions trading systems around the world. Presently, there are now 17 systems ETS in force across four continents, including European Union (EU), Switzerland, Canada (Québec), United States (Regional Greenhouse Gas Initiative [RGGI], California), New Zealand, Kazakhstan, China (Chongqing, Beijing, Tianjin, Shanghai, Hubei, Shenzhen, Guangdong), Republic of Korea and Japan (Tokyo, Saitama). GHG emissions covered by ETS is approximately seven billion tons (16% of global GHG emissions), and currently, there are ongoing trading worth more than four billion tons of GHG emissions. All together, these jurisdictions produce around 40% of global gross domestic product (GDP). Eleven governments at several levels (countries, states or provinces and cities) are considering an ETS as the effective mechanism to reduce their GHG emissions, including United States (Washington), Mexico, Brazil (Rio de Janeiro, São Paulo), Chile, Turkey, Russia, Japan, Taiwan, Vietnam and Thailand (International Carbon Action Partnership [ICAP], 2015b, 2016a). The global ETS map in Figure 2.4 illustrates ETS in force, scheduled and under consideration.

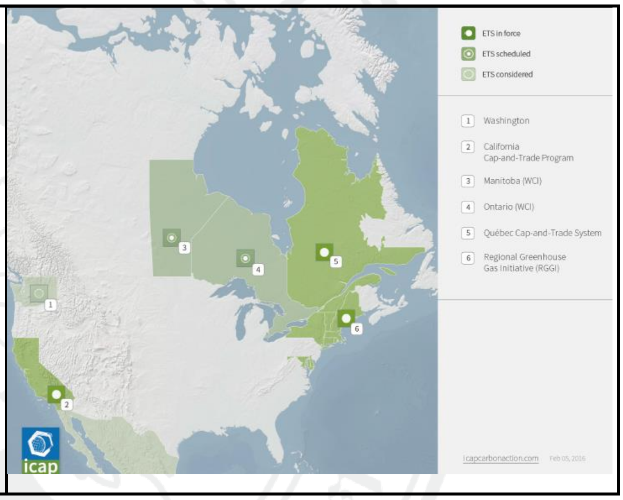
Generally, the ETS should be applied for sectors with high intensive energy consumption (Usapein & Chavalparit, 2017) such as electricity generation, petrochemical, iron and steel and other industries. The information of ETS regulations around the world, including type of cap and allocation, overall GHG reduction target, sectors and thresholds coverage can be found in Table 2.2 and Table 2.3





(A) Asia

(B) Europe and Central Asia



(C) Latin America and the Caribbean

(D) North America

(E) Pacific

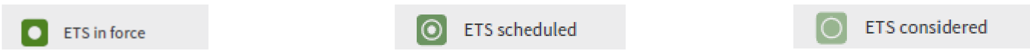


Figure 2.4 Emissions Trading Systems around the World in Year 2016
Source: International Carbon Action Partnership [ICAP] (2016a)

Table 2.2 The Information of ETS Regulations around the World

Name of ETS	Status	Type of Cap	Allocation	Overall GHG reduction target	Sectors covered and thresholds
EU-ETS	ETS in force	Absolute	Auctioning & free allocation	By 2020: 20% below 1990 GHG levels By 2030: 40% below 1990 GHG levels By 2050: 80-95% below 1990 GHG levels	- Power and heat generation - Industry including oil refineries, coke ovens, petrochemicals, iron and steel, cement, glass, lime, bricks, ceramics, pulp, paper and board - Commercial aviation (>10,000 t CO_2/year)
Canada - Québec Cap-and-Trade System	ETS in force	Absolute	Auctioning & free allocation	By 2020: 20% below 1990 GHG levels By 2030: 37.5% below 1990 GHG levels By 2050: 80-95% below 1990 GHG levels.	- Electricity (>25,000 CO_2e/year) - Industry (>25,000 CO_2e/year). - Transport and building (>25,000 tCO_2e/year)
USA - California Cap-and-Trade Program	ETS in force	Absolute	Auctioning & free allocation	By 2020: return to 1990 GHG levels. By 2040: 40% below 1990 GHG levels. By 2050: 80% below 1990 GHG levels.	- Industry including cement, glass, iron and steel, lead, lime, petroleum and natural gas, petroleum refining, pulp and paper, electricity generation (>25,000 tCO_2e/year.)
USA - Regional Greenhouse Gas Initiative (RGGI)	ETS in force	Absolute	Auctioning	By 2020: 50% reduction from 2005 GHG levels.	- Fossil fuel electric generating (> 25MW)
Kazakhstan Emissions Trading System (KAZ ETS)	ETS in force	Absolute	Free allocation	BY 2020: 15% reduction from 1990 GHG levels. By 2030: 15–25% reduction from 1990 GHG levels	- Energy sector (including oil and gas,) mining and chemical industry (>20,000tCO_2/year)

Name of ETS	Status	Type of Cap	Allocation	Overall GHG reduction target	Sectors covered and thresholds
China - Beijing pilot system	ETS in force	Absolute	Free allocation	By 2015: 18% reduction in carbon intensity compared to 2010 levels	- Electricity and heat (>10,000tCO_2/year) - Industry including cement, petrochemicals, iron and steel, other industrial and services (>10,000tCO_2/year)
China-Chongqing pilot system	ETS in force	Absolute	Free allocation	By 2015: 17% reduction in carbon intensity compared to 2010 levels	- Power - Industry including aluminum, ferroalloys, calcium carbide, cement, caustic soda, and iron and steel (>20,000 tCO_2e/year)
China-Guangdong pilot system	ETS in force	Absolute	Auctioning & free allocation	By 2015: 19.5% reduction in carbon intensity compared to 2010 levels.	- Energy (>20,000 tCO_2e/year) - Industry including iron and steel, cement, petrochemicals, ceramics, textiles, nonferrous metals, chemicals, pulp and paper, construction, transportation (>20,000tCO_2/year or energy consumption 10,000 tons coal equivalent (tce) /year)
China - Hubei pilot system	ETS in force	Absolute	Auctioning & free allocation	By 2015: 17% reduction in carbon intensity compared to 2010 levels.	- Power and heat - Industry including iron and steel, chemicals, petrochemicals, cement, automobile, ferrous metals, glass, paper, food and beverage (energy consumption > 60,000 tons coal equivalent (tce) /year)
China - Shanghai pilot system	ETS in force	Absolute	Auctioning & free allocation	By 2015: 19% reduction in carbon intensity compared to 2010 levels.	- Electricity (>20,000t CO_2e/year) - Industry including chemicals, iron and steel, petrochemicals, ports, non-ferrous metals, building materials, paper, rubber, textiles, paper, rubber (>20,000 tCO_2/year) - Non-industry including airports, aviation, hotels railways (>10,000 tCO_2/year)

Name of ETS	Status	Type of Cap	Allocation	Overall GHG reduction target	Sectors covered and thresholds
China - Shenzhen pilot system	ETS in force	Absolute	Auctioning & free allocation	By 2015: 21% reduction in carbon intensity compared to 2010 levels	- Power, manufacturing (>3,000 tCO_2e/year) - Buildings (>20,000 m^2 for public buildings and 10,000 m^2 for government buildings)
China - Tianjin pilot system	ETS in force	Absolute	Free allocation	By 2015: 19% reduction in carbon intensity compared to 2010 levels.	- Heat and electricity production (>20,000 tCO_2e/year) - Industry including iron and steel, petrochemicals, chemicals, exploration of oil and gas. (> 20,000 tCO_2/year)
Japan - Tokyo Cap-and-Trade Program	ETS in force	Absolute	Free allocation	By 2020: 25% below 2000 GHG levels. By 2030: 30% below 2000 GHG levels.	- Commercial and Industrial (energy consumption > 1,500 kL of crude oil equivalent / year
Japan - Saitama Emissions Trading System	ETS in force	Absolute	Free allocation	By 2020: 21% reduction from 2005 GHG levels	- Commercial and Industrial (energy consumption > 1,500 kL of crude oil equivalent / year
Korea Emissions Trading Scheme	ETS in force	Absolute	Free allocation	By 2020: 30% below BAU. By 2030: 37% below BAU (22% below 2012 GHG levels)	- Industry including power, steel, cement, refinery petrochemical (> 125,000 tCO_2/year) - Business including buildings, aviation (>25,000 tCO_2/year)
Washington	ETS under consideration	No information available yet		By 2020: reduce emissions to 1990 GHG levels. By 2035: 25% reduction from 1990 GHG levels. By 2050: 50% reduction from 1990 GHG levels	No information available yet

Name of ETS	Status	Type of Cap	Allocation	Overall GHG reduction target	Sectors covered and thresholds
Taiwan	ETS under consideration	No information available yet		By 2050: 50% below 2005 GHG levels.	No information available yet
Thailand	ETS under consideration	No information available yet		By 2020: 7-20% reduction compared to BAU in the energy and transport sectors (NAMA Submission) By 2030: 20-25% reduction compared to BAU (INDC Submission)	No information available yet
Vietnam	ETS under consideration	No information available yet		By 2020: 20% reduction from 2010 GHG (intensity) levels By 2030: 8% below BAU	No information available yet

Source: International Carbon Action Partnership [ICAP] (2016b)

Table 2.3 The Sector Coverage of ETS in Force around the World

Name of ETS	Sectors											
	Electricity	Oil refineries	Petro-chemicals	Iron and steel	Cement	Glass	Pulp and paper	Lime	Chemical	Aviation	Transporta-tion	Building
EU-ETS	●	●	●	●	●	●	●	●	●	●		
Canada-Québec	●										●	●
USA-California	●	●	●	●	●	●	●	●				
USA-RGGI	●											
KAZ ETS		●							●			
China-Beijing	●		●	●	●							
China-Chongqing	●			●	●				●			
China-Guangdong	●		●	●	●		●		●		●	
China-Hubei	●		●	●	●	●	●		●			
China-Shanghai	●		●	●			●		●	●	●	●
China-Shenzhen	●											●
China-Tianjin	●		●	●					●			
Korea	●	●	●	●	●					●		●
Japan-Tokyo	Commercial and Industrial (energy consumption > 1,500 kL of crude oil equivalent / year											
Japan- Saitama	Commercial and Industrial (energy consumption > 1,500 kL of crude oil equivalent / year											

2.2.2 Carbon Emission Trading in Thailand

Thailand Voluntary Emission Trading Scheme (Thailand V-ETS) was established as a pilot project on October 1, 2014, as one of the important carbon mitigations in Thailand and it was continuously developed by Thailand Greenhouse Gas Management Organization (TGO). Thailand V-ETS as a pilot system has been designed to meet the measurement, reporting and verification system (MRV) accordance with ISO 14064-1, 14064-3, 14065 (International Standard Organization, 2006) and GHG Protocol Corporate Accounting and Reporting Standard (WRI/WBCSD, 2005). MRV system is a tool for ETS that contributes to the system reliability. The implementation of Thailand V-ETS roadmap is illustrated in Figure 2.5

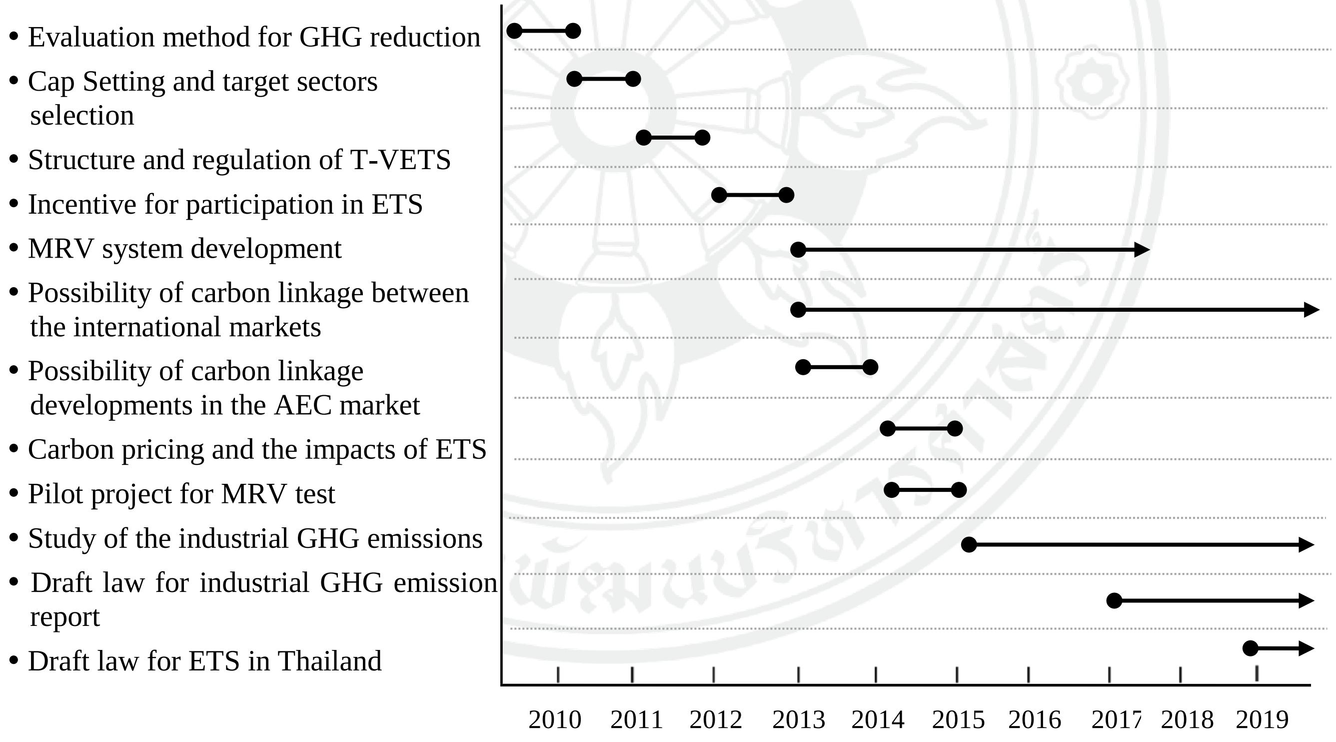


Figure 2.5 Overview of Thailand V-ETS Roadmap

Source: Adapted from TGO (2016)

As Figure 2.5 demonstrate the development direction of carbon emission trading in Thailand. By 2019, Thailand V-ETS will designate for the draft law of ETS with the focus on the highly intensive energy sectors including electricity, cement, petrochemicals and iron and steel. At present, the system is in the process of establishing an ETS and pilot operation testing. There are currently 18 and 19 firms participating under system in fiscal year 2015-2016 (Thailand Greenhouse Gas Management Organization (Public Organization) [TGO], 2016) listed in Table 2.4

Table 2.4 List of Pilot Participants under Thailand V-ETS in Fiscal year 2015-2016

Fiscal year 2015	Fiscal year 2016
Electricity sector	***Cement sector***
1. Mae Mo power plant (machines 4-7)	1. TPI Polene public company limited
2. Bangpakong power plant (machines 1-2)	2. Siam city cement public company limited
3. Phra Nakhon Tai power plant (machines 1-2)	3. The Siam Cement (Lampang) Co.,Ltd
4. Wangnoi power plant (machines 1-4)	4. The Siam Cement (Thung Song) Co.,Ltd
5. Krabi power plant	***Iron and steel sector***
6. Chana power plant (machines 1)	5. GJ Steel public company limited
7. Numpong power plant	6. The Siam Construction Steel Co.,Ltd
8. Gulf JP KP1 Co., Ltd	7. Sahaviriya Steel Industries Co., Ltd
9. Gulf JP KP2Co., Ltd	8. Thai Cold Rolled Steel Sheet Public Co., Ltd
10.GULF Power Generation Co., Ltd	***Pulp and paper sector***
11.Ratchaburi Electricity Generating Holding public company limited	9. Fiber Pattana Co., Ltd
Petrochemicals sector	10.Thai Cane Paper public company limited.
12.Vinythai public company limited	11.Siam Cellulose Co., Ltd (Wang Sala plant)
13.PTT Global Chemical public company limited Branch 2	12.CAS Paper Mill Co.,Ltd.
14. PTT Global Chemical public company limited Branch 3	***Petrochemicals sector*** *(continued from fiscal year2015)*
15.PTT Global Chemical public company limited Branch 4	13.PTT Global Chemical public company limited Branch 2
16.PTT Global Chemical public company limited Branch 5	14.PTT Global Chemical public company limited Branch 3
17.PTT Global Chemical public company limited Branch 11	15.PTT Global Chemical public company limited Branch 4
18.Rayong Olefins Co.,Ltd	16. PTT Global Chemical public company limited Branch 5
	17. PTT Global Chemical public company limited Branch 11
	18. Rayong Olefins Co., Ltd
	19. Vinythai public company limited

Source: Thailand Greenhouse Gas Management Organization (Public Organization) [TGO] (2016)

After the pilot Thailand V-ETS first phase was implemented in year 2014-2017, the overview result of system evaluation showed that the participants decided to set the cap by using carbon intensity and emission permits allocated by grandfathering based the average of carbon intensity of reference year as it provides more flexibility than the absolute target. However, cap setting base on carbon intensity is difficult for the regulator to administrate because GHG reduction for each year remains unknown (Usapein & Chavalparit, 2017). The results of Thailand V-ETS evaluation are summarized in Table 2.5.

Table 2.5 Summarized the Attributes of the Thailand V-ETS

Authority	:	Thailand Voluntary Emission Trading System (Thailand V-ETS) was launched as a pilot project in 2014.
Target sectors	:	High energy intensive sectors, such as power plants, cement, iron and steel, petrochemical, refineries and other sectors
The number of participants joined in the first phase of Thailand V-ETS	:	30 plants joined the first phrase: 11 Power plants, 7 Petrochemical plants, 4 Cement plants, 4 Iron and steel plants and 4 Pulp and paper plants
Reference year	:	Year 2012-2013 (average carbon intensity)
Type of carbon cap	:	2% GHG reduction based on the carbon intensity of the reference year
Allowance allocation	:	Grandfathering
Period of operation	:	3 years

Source: Adapted from Usapein and Chavalparit (2017)

2.3 Thailand's Climate Change Policies

2.3.1 Thailand's Climate Change Master Plan 2015 – 2050

Thailand's Climate Change Master Plan is a framework of integrated policies and action plans relating to climate change. Its purpose is to support climate change preparedness relevant to Thailand's economic and socio-cultural contexts as well as sufficiency economy philosophy. The Master Plan has objectives to guide actions to mitigate and tackle problems arising from climate change, promote the conduct of appropriate and effective action plans in all sectors and levels, and encourage Thailand to move towards low carbon society in accordance with sufficiency economy philosophy.

The mission of Thailand's Climate Change Master Plan 2015 – 2050 are 1) To encourage all related parties to take part in reducing greenhouse gas emissions on the basis of sustainable development and co-benefits in the context of Thai society, 2) To work with the global community in solving the issue of climate change without producing negative impacts on the country's economic, social and environmental development, and 3) To promote the adjustment of the economic and social structures to gain immunity impediment against interference of the nation's development and competitiveness in transitioning Thailand into a low-carbon society. The aim of master plan is Thailand able to continue its economic, social, and environmental developments in accordance with sufficiency economy philosophy and to reduce greenhouse gas emissions by 2050, without impeding the country's gross domestic product (GDP) or reducing its growth of developmental capability and competitiveness.

2.3.2 The 12th National Economic and Social Development Plan 2017-2021

The 12th National Economic and Social Development Plan (NESDP) targets on major issues including social disparity, strong and competitive economy, natural capital preservation and environmental quality for environmentally friendly growth, energy and water resource security, food security, social security, unity, independence and sovereignty and gain the confidence of the international level and the public administration transparent, accountable, efficient, power distribution and public participation. The one of the main goals that is related to climate change is on the 4th strategy: Environmentally friendly growth for sustainable development by the following 4 targets, including 1) Rehabilitation of natural resources and the sustainable and equitable use, 2) Establish water security of the country and water resources management system to be effective, 3) Environmental management to reduce pollution and provide better quality and 4) Capacity development to greenhouse gases reduction and adaptation to the impacts of climate change and disaster management.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Conceptual Framework

Thailand Voluntary Emission Trading System (Thailand V-ETS) is the first voluntary CO_2 emission trading system in Thailand and was launched as pilot project in 2014. Its development remains under the responsibility of Thailand Greenhouse Gas Management Organization (TGO). Thailand V-ETS is a scheme to assess the feasibility of system before establishing the carbon ETS in Thailand. Thailand V-ETS focuses on the highly intensive energy sectors, especially which associated with the electricity, cement, petrochemicals, iron and steel, and aviation.

Generally, the carbon ETS would result in a positive effect on carbon mitigation and energy efficiency improvement but will have a negative impact on the economy. Carbon ETS works on the principle of cap and trade which provides economic incentive for polluter to achieve the emission targets at minimum cost. In theory, ETS regulators will set a limit of the total CO_2 emissions (Cap) and then allocate a quota of allowances to each participant. The market mechanism decides the trading in emission permits. The cap or CO_2 limitation of participants under ETS system will lead to increase in production cost and product price, thus slowdown of the economic growth. In addition, the impacts of the product price increase would affect their supply chain both backward linkages (upstream production sectors) and forward linkages (downstream production sectors). Therefore, cap setting, and allocation methodology must consider the different economic linkages for the distribution of CO_2 quota emission permits to participants.

This study employs the Input - Output model as a tool for evaluating the backward linkages and forward linkages based on input-output table of Thailand in 2010 by Office of the National Economics and Social Development Board (NESDB). Thailand's input-output table comprise of 180 production and service activities and 180 commodities and services.

The framework of estimating CO_2 emission considered only direct CO_2 emissions related to fossil fuels combustion of sectors which are likely to participate in Thailand ETS. Fossil fuels are divided into three types: coal, petroleum, and natural gas. Coal and its products include anthracite, bituminous, lignite, coke, briquettes and other coal. Petroleum products include diesel, gasoline, fuel oil, kerosene, jet fuel, and liquid petroleum gas (LPG). The data for fossil fuels consumption are based on the input-output table of Thailand in 2010 which is related to the proportion of raw data obtained from Bureau of Energy Regulation and Conservation, and the secondary data was from Thailand energy situation in 2010 and Energy balance of Thailand in 2010 by Department of Alternative Energy Development and Efficiency, Ministry of Energy. The GHG emissions (in term of CO_2e) calculations followed the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Intergovernmental Panel on Climate Change [IPCC], 2006). It was calculated using the stationary and mobile combustion emission factor for GHG inventories from IPCC (2006) Vol.2 table 2.2, DEDE and The United States Environmental Protection Agency (United States Environmental Protection Agency [EPA], 2014).

The participants under Thailand ETS must be focused on the highly intensive energy consumption and significant amount of GHG emissions. Thailand ETS participating sectors include petrochemical, cement, iron and steel, electricity, and aviation. The implementation of the Thailand ETS can be expected to effect change in the economy. Emission reduction involves extra investment and spending, thereby raising cost and price of goods and services of various industries that are interdependent. Industries are connected as inputs are drawn from other industries and output is used by other industries. The scope of market differs for respective industries. Likewise, the scope of input requirements differs for respective industries. A complete account of cost of emission reduction, thus, involves cost borne by initiating industry and cost borne by dependent industries. The interdependence is both direct and indirect. The cost of emission reduction borne by the interdependence of industries is external to initiating industry. Trade of emission in a market is driven by internal cost of initiating industry. Emission quota is allocated by equilibrium of demand and supply. The market, however, does not account for cost that is external to initiating industry. If external cost is taken account, the allocation of quota needs to be altered to minimize cost for the whole system. As external cost is public in nature, the allocation of GHG emission quota based on external cost requires a management by a public agency.

This study aims to allocate CO_2 emission quotas of different industries in Thailand ETS, based on the equi-marginal principle by considering the economic impact as the external cost of each sector participating in the system. The cap setting level are determined at 2-5% GHG reduction based on the reference year. Different aggregate economic cost of carbon quotas allocated based on the equi-marginal principle and grandfathering (GF) or fixed allocation is compared. The results could be used as guidelines for the optimal allocation of carbon quotas in Thailand ETS among sectors to achieve economic efficiency and minimization of social economic cost. The conceptual framework of this study is shown in Figure 3.1

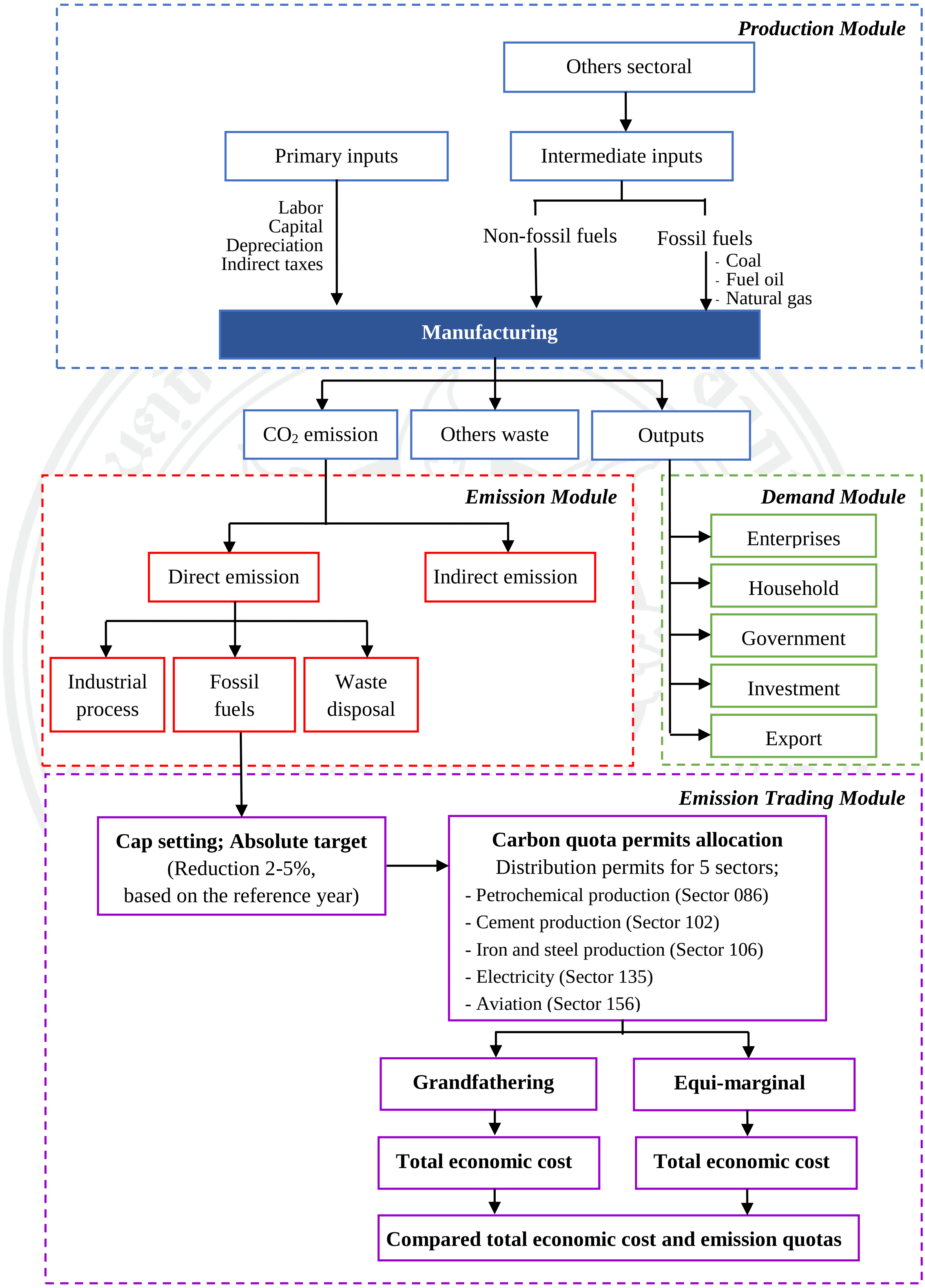


Figure 3.1 Conceptual Framework of Carbon Emission Quotas Allocation in Thailand ETS for Achieving Economic Efficiency

3.2 Methodology

3.2.1 Data Sources

3.2.1.1 Input-Output Table

The latest input-output (I-O) table of Thailand for 2010 released by Office of the National Economics and Social Development Board (NESDB), which represents the Thai economy with the total of 180 commodities, is used for the computation of the backward and forward linkages. The codes 001-041 are used for agricultural and primary commodities, whereas the codes 042-134 are used for the manufacturing commodities, and the codes 135-180 are used for the services.

The I-O table was developed by Wassily Leontief and is considered to be a powerful analytical tool for describing the structure of the economy. The table provides detailed linkage and relationships between information on production activities and transaction value in products of the economy. The input-output table representing each sector's production of the goods and services used as inputs to produce its output are expressed in the column perspective; the demand of product (output) for intermediate input that are used in production process and final consumption are expressed in the row perspective.

The structure of input-output table has n rows and n columns:

- The horizontal row (i^{th}) perspective expressed as output (product) distribution consist of: (1) intermediate input (inter-industry demand); and (2) final consumption, including investment expenditure, household consumption, government consumption, inventories, exports, and special export.
- The vertical column (j^{th}) perspective expressed as input requirements for production of goods and services activities (demand) consist of: (1) primary input (value added), including labor wage income, capital, depreciation, and indirect taxes; and (2) intermediate input, consist of domestic, and import.

The component of input-output table is shown in Figure 3.2 and the definition of I-O code can be found in Appendix 1.

Industrial sectors

		Intermediate Input ($X0D_{i,j}$)						Final Demand (F)						
		Sec 1	Sec 2	Sec 3	Sec 4	…	Sec 180	Investment	Household	Government	Inventories	Export	Special Export	**Total Output (X_i)**
Commodities (Domestic)	Sec 1	$X0D_{1,1}$	$X0D_{1,2}$	$X0D_{1,3}$	$X0D_{1,4}$	…	$X0D_{1,180}$	$F1D_1$	$F2D_1$	$F3D_1$	$F4D_1$	$F5D_1$	$F6D_1$	$\mathbf{X_1}$
	Sec 2	$X0D_{2,1}$	$X0D_{2,2}$	$X0D_{2,3}$	$X0D_{2,4}$	…	$X0D_{2,180}$	$F1D_2$	$F2D_2$	$F3D_2$	$F4D_2$	$F5D_2$	$F6D_2$	$\mathbf{X_2}$
	…	…	…	…	…	…	…	…	…	…	…	…	…	**…**
	Sec 180	$X0D_{180,1}$	$X0D_{180,2}$	$X0D_{180,3}$	$X0D_{180,4}$	…	$X0D_{180,180}$	$F1D_{180}$	$F2D_{180}$	$F3D_{180}$	$F4D_{180}$	$F5D_{180}$	$F6D_{180}$	$\mathbf{X_{180}}$
Commodities (Import)	Intermediate Input($X0I_{i,j}$)													Total Import Demand
		Sec 1	Sec 2	Sec 3	Sec 4	…	Sec 180							
	Sec 1	$X0I_{1,1}$	$X0I_{1,2}$	$X0I_{1,3}$	$X0I_{1,4}$	…	$X0I_{1,180}$	$F1I_1$	$F2I_1$	$F3I_1$	$F4I_1$			
	Sec 2	$X0I_{2,1}$	$X0I_{2,2}$	$X0I_{2,3}$	$X0I_{2,4}$	…	$X0I_{2,180}$	$F1I_2$	$F2I_2$	$F3I_2$	$F4I_2$			
	…	…	…	…	…	…	…	…	…	…	…			
	Sec 180	$X0I_{180,1}$	$X0I_{180,2}$	$X0I_{180,3}$	$X0I_{180,4}$	…	$X0I_{180,180}$	$F1I_{180}$	$F2I_{180}$	$F3I_{180}$	$F4I_{180}$			
Value Added	Labor ($X1_j$)	$X1_1$	$X1_2$	$X1_3$	$X1_4$	…	$X1_{180}$							Sum of Labor (VA1)
	Capital ($X2_j$)	$X2_1$	$X2_2$	$X2_3$	$X2_4$	…	$X2_{180}$							Sum of Capital (VA2)
	Indirect taxes ($X3_j$)	$X3_1$	$X3_2$	$X3_3$	$X3_4$	…	$X3_{180}$							Sum of Indirect taxes (VA3)
Total Input (X_j)		$\mathbf{X_1}$	$\mathbf{X_2}$	$\mathbf{X_3}$	$\mathbf{X_4}$	**…**	$\mathbf{X_{180}}$							

Figure 3.2 General Structure of Input-Output Table

3.2.1.2 Fossil Fuels Consumption

Since there is no official statistics on CO_2 emissions in each industry in Thailand ETS, the existing study usually construct the data on the basis of fossil fuel consumption value on I-O table, which is the main source of CO_2 emissions. The data for fossil fuels consumption are drawn from the input-output table of Thailand released in 2010. Other sources of data include the Bureau of Energy Regulation and Conservation, and the Department of Alternative Energy Development and Efficiency. CO_2 emission is computed from the input-output table of Thailand released in 2010. Fossil fuels are scoped to include coal, petroleum, and natural gas. Coal and its products, consist of anthracite, bituminous, lignite, coke, briquettes and other coal. Petroleum products consist of diesel, gasoline, fuel oil, kerosene, jet fuel, and liquid petroleum gas (LPG).

3.2.2 Evaluation of The Economic Impact using Input-Output Model

3.2.2.1 Input-Output Model

Input-output (I-O) matrix model formulated by Wassily Leontief (Kurz, Dietzenbacher, & Lager, 1998; Leontief, 1986) is the tool of economic analysis used to forecast the effect of changes in initial economic activity that involves multiple sectors economy. The I-O model analysis is usually based on I-O transaction table that provides the database of intermediate input in the production and the distribution of all output in an economy. The main principle of the I-O model is the intermediate transaction data in the matrix which balances the total demand and total supply among the industries (Perese, 2010). The mathematical formula represents the relationship between total output from industry *i*, domestic intermediate input (X_{ij}) for production and final demand (F_i) as presented in the following balance equation (Duchin & Steenge, 2007; Fujio & Tanaka, 2011; Ronald & Peter, 2009):

$$X_i = \sum_{j=1}^{n} X_{ij} + F_i \qquad i = 1,\ldots,n \qquad (1)$$

where

X_i is the total output from industry *i*

X_{ij} is the amount of output from industry *I* used as input for industry *j* (*j*=1,…,*n*)

F_i is the final demand of commodity *i*

a_{ij}, defined as the input coefficient, refers to the proportion of input (X_{ij}) quantity required for the produce one unit of output from industry *j*.

$$a_{ij} = \frac{X_{ij}}{X_j} \qquad (2)$$

$$X_{ij} = a_{ij}X_j \qquad (3)$$

where

a_{ij} is the input coefficient on production of industry *j*

X_j is the total output from industry *j*

Input coefficient (a_{ij}) can be calculated and substituted into Equation (1), rewritten as the formula below:

$$X_i = \sum_{j=1}^{n} a_{ij}X_j + F_i \qquad i = 1,\ldots,n \qquad (4)$$

The Equation (4) can be written in matrix format as:

$$\begin{bmatrix} X_1 \\ X_2 \\ : \\ X_n \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{1n} \\ a_{21} & a_{22} & a_{2n} \\ : & : & : \\ a_{n1} & a_{n2} & a_{nn} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ : \\ X_n \end{bmatrix} + \begin{bmatrix} F_1 \\ F_2 \\ : \\ F_n \end{bmatrix} \qquad (5)$$

In Equation (5) can be expressed in a matrix algebra notation as follows:

$$X = AX + F \qquad (6)$$

In Equation (6) can be written

$$X - AX = F \qquad (7)$$

$$(I - A)X = F \qquad (8)$$

$$X = (I - A)^{-1} F \qquad (9)$$

where

X is the domestic production column vector

F is the final demand column vector

I is an identity matrix

A is the input coefficient matrix

$(I - A)^{-1}$ is the inverse matrix of (I – A), often known as the Leontief inverse

The Equation (9) represents the relationship between final demand and domestic production. The term inverse matrix $[(I - A)^{-1}]$ is Leontief multiplier, which is the core of the I-O model. This multiplier matrix can measure the changes of total input throughout the economy required to produce one unit of product change for industry *i*. For example, the production of an additional one unit of cement requires input such as limestone, coal, electricity and other inputs. The amount of supplementary both direct and indirect input requirements from all sectors in an economy that is needed to fulfill the final demand for a given sector can be calculated using the Leontief inverse.

3.2.2.2 Evaluation of Economic Impacts

Industry interdependence, the degree and scope of interdependence are commonly quantified as the value of linkages, which are traditionally identified as backward in accounting for the intermediate use of other products for inputs, and as forward in accounting for the intermediate use of the product. The value of linkages is measured from Leontief's inverse computed from the input-output model equation using the data from an input-output table.

The Leontief's inverse is recognized as taking into account both direct and indirect relationships between industries. Based on these properties, the combined strength of backward and forward linkages can be used to represent the economic impact of GHG emission reduction as the cost is transmitted to other industries in the range of the backward and forward linkages. This study employs the Leontief multiplier in I-O model as the tool for evaluating the economic impact for several sectors in the economy that are likely to participate in Thailand ETS.

The economic impact effect of industry production has two main categories: (1) Backward linkage effect related to the intermediate input demands from other sectors to the productions of industry *i*, and (2) Forward linkage effect related to output utilization of industry *i* into the production of another industry as intermediate inputs (Drejer, 2002; Jiemin & Mark, 2000).

The backward and forward linkages analysis is an important tool for measuring the interdependence of production sectors in terms of the magnitude transactions in an economy (Kula, 2008). The economic impact can be estimated from the Leontief inverse matrix. The value of backward linkages is used to measure the multiplier of economic impacts at economy wide scale initiated by change in final demand whereas the forward linkages is used to measure the significance of the particular product at the economy wide scale. The strength of backward linkages is measured by the column sum of Leontief's inverse whereas the forward linkages is measured by the row sum as follows:

Backward linkages

$$L_j^B = \sum_{i=1}^{180} (I - A)_{ij}^{-1} \qquad (10)$$

Forward linkages

$$L_i^F = \sum_{j=1}^{180} (I - A)_{ij}^{-1} \qquad (11)$$

The sum of forward and backward linkages is used to account for the economic impact of GHG emission reduction as follows:

$$\text{Economic impact} = L_j^B + L_i^F \qquad (12)$$

3.2.3 Estimation of CO_2 Emissions from Fossil Fuels Combustion

The amount of CO_2 emission of the five industries target in Thailand ETS focused on direct CO_2 emissions related from fossil fuels combustion. Fossil fuels are divided into three types: coal, petroleum, and natural gas. Coal and its products include anthracite, bituminous, lignite, coke, briquettes and other coal. Petroleum products include diesel, gasoline, fuel oil, kerosene, jet fuel, and liquid petroleum gas (LPG). The direct CO_2 emissions (in term of CO_2e) are calculated following the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Intergovernmental Panel on Climate Change [IPCC], 2006).

3.2.3.1 Calculations of the Fossil Fuel Consumption

The data for fossil fuels consumption drawn from the input-output table of Thailand released in 2010 are shown in Baht value. Coal and lignite are shown in sector 030, petroleum refineries in sector 093, and gas in sector 136. It is calculated by contribution the fuel quantity ratio from Thailand energy situation in 2010 into the fuel consumption value on I-O table, then convert to fuel consumption by fuel price of each individual fossil fuel. The quantity of fossil fuel consumption is computed by

$$FC_j = \sum_{k=1}^{12} \frac{FV_k}{P_k} \qquad (13)$$

Where

k is the types of fossil fuels (k = 1,…,*12*) as shown in Table 3.1

FC_j is the fossil fuel consumption in physical unit of industry *j*

FV_k is the fossil fuel consumption value in I-O table of fuel type *k*

P_k is the fossil fuel price in 2010 of fuel type *k*

Table 3.1 The Classification of Fossil Fuels

Type of fossil fuels	Code
Coal and its products	
- Anthracite	k_1
- Bituminous	k_2
- Lignite	k_3
- Coke	k_4
- Briquttes and other coal	k_5
Petroleum oil products	
- Diesel	k_6
- Gasoline	k_7
- Fuel oil	k_8
- Kerosene	k_9
- Jet fuel	k_{10}
- Liquefied Petroleum Gas (LPG)	k_{11}
Natural gas	
- Natural gas	k_{12}

3.2.3.2 Estimation of Direct CO_2 Emissions

Total direct CO_2 emission (E) from fossil fuels combustion are calculated using the stationary and mobile combustion emission factor (EF) for GHG inventories from IPCC (2006) Vol.2 Table 2.2, DEDE and The United States Environmental Protection Agency (United States Environmental Protection Agency [EPA], 2014) as shown in Table 3.2. The CO_2 emissions (in term of CO_2 equivalent; CO_2e) are estimated by the following equation:

$$E_j = \sum_{k=1}^{12} (FC_k \times EF_k) \quad (14)$$

Where

E_j is the direct CO_2 emission (in term of CO_2e) of industry *j*

FC_k is the consumption of fossil fuel type *k* of industry *j*

EF_k is the CO_2 emission factor from combustion of fuel type *k*

3.2.3.3 Estimation of CO_2 Emissions Intensity

The CO_2 emission intensity (EI) is defined as the ratio of the total CO_2 emission per output unit of industry *j* expressed as below:

$$EI_j = \frac{E_j}{X_j} \quad (15)$$

Where

EI_j is the CO_2 emission intensity of industry *j*

E_j is the total CO_2 emission of industry *j*

X_j is the total output from industry *j*

Table 3.2 The GHG Emission Factor for Fossil Fuels Combustion

Type of Fossil Fuels	**Units**	**GHG Emission (kg CO_2e/unit)**	**Sources**
Stationary Combustion			
Coal and its products			
- Anthracite	kg	3.1014	IPCC, 2006
- Bituminous	kg	2.3440	IPCC, 2006
- Sub-bituminous	kg	2.5466	IPCC, 2006
- Lignite	kg	1.0624	IPCC, 2006
- Coal coke	kg	2.8377	US EPA, 2014
- Brown coal briquettes	kg	2.0182	IPCC, 2006
Petroleum oil products			
- Crude oil	litre	2.4805	IPCC, 2006
- Diesel	litre	2.7080	IPCC, 2006
- Gasoline	litre	2.2376	IPCC, 2006
- Fuel oil	litre	3.0883	IPCC, 2006
- Kerosene)	litre	2.4777	IPCC, 2006
- Liquefied Petroleum Gas (LPG)	litre	1.6812	IPCC, 2006
Natural gas			
- Natural gas	scf	0.0573	IPCC, 2006
- Natural gas	kg	2.2472	IPCC, 2006
- Liquefied Natural Gas (LNG)	kg	2.8500	IPCC, 2006
Mobile Combustion			
- Jet kerosene	litre	2.4910	US EPA, 2014

Sources: Intergovernmental Panel on Climate Change [IPCC] (2006); United States Environmental Protection Agency [EPA] (2014)

3.2.4 Simulation of Economic Impact - Emission Ratio (EIER)

The EIER is constructed from the fact that the economic impact is produced by the CO_2 emission reduction. The inverse linear relationship between economic impact and the amount of CO_2 emission is simply assumed to represent the marginal cost of CO_2 emission reduction. The linear relationship is such that the economic impact expressed in terms of economic contraction becomes more significant as the CO_2 emission is reduced. The EIER for respective targeted industries is constructed as the ratio between the economic impact and the amount of existing CO_2 emission, as illustrated in Figure 3.3. The economic impact is represented by the sum of the value of backward and forward linkages. This representation is based on the fact that the reduction of CO_2 emission effects in rising cost and contraction of demand and output which extend from the targeted industries to their direct and indirect suppliers and customers. The larger the reduction, the greater will be the impacts.

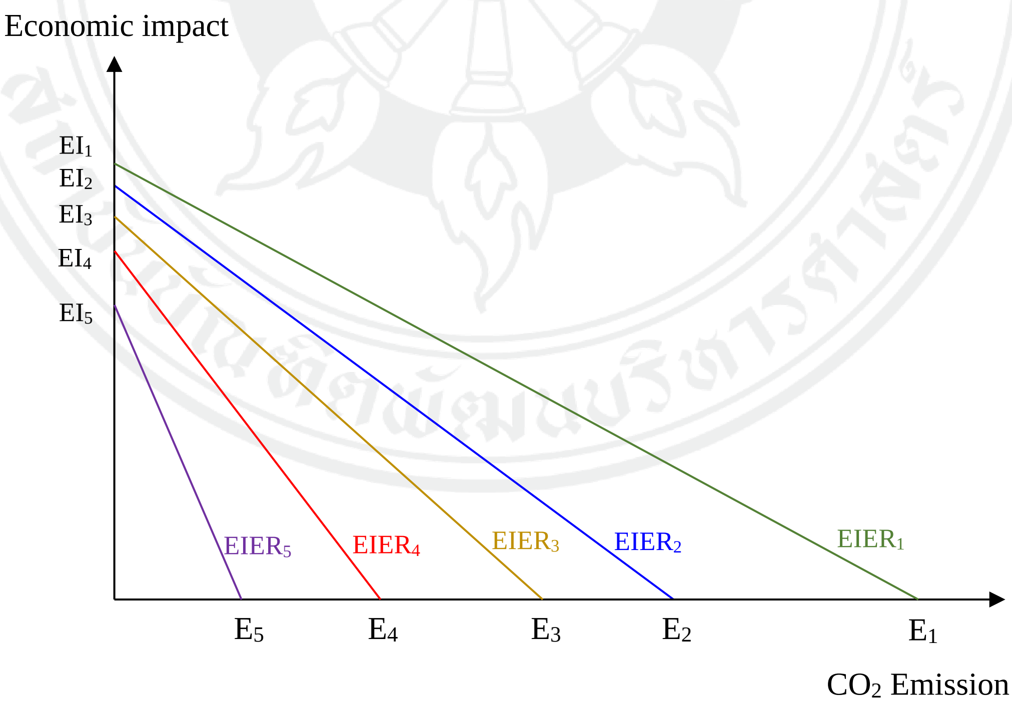


Figure 3.3 The Ratio of Economic Impact and CO_2 Emission of Different Industries

Figure 3.3 illustrates the inverse linear relationship between economic impact and the CO_2 emission, which can be expressed in a general linear equation as follow:

$$EI_j = -a_jE_j + C_j \qquad (16)$$

Where EI_j is the economic impact of industry *j*, which represents the Y-intercept

a_j is the ratio between the economic impact and CO_2 emission (EIER) of industry *j*, which represents the slope of the linear equation

E_j is the total CO_2 emission of industry *j*

C_j is the constant in the linear equation of industry *j*, which represents value of the EI_j when E_j takes the zero value

The EIER is the ratio between the economic impact and the amount of CO_2 emission, which is constructed as the change in the economic impact per additional unit of reduction of CO_2 emission. This is symbolically denoted by

$$EIERj = -\Delta EI_j/\Delta E_j \qquad (17)$$

3.2.5 Estimation of Proportional Allocation

The cap of total quantity of CO_2 emission, denoted by the term E_{Target}, is determined by Thailand ETS to achieve 2-5% reduction. The sum of CO_2 emission of respective industry, denoted by the term Q_j, is set as follows.

$$E_{target} = \sum_{j=1}^{n} Q_j \qquad (18)$$

Where E_{target} is the total CO_2 emission target

Q_j is the CO_2 emission quotas distributed to industry *j*

3.2.5.1 The Emission Quota Allocation by the Grandfathering Method

Accordingly, each industry is obliged to reduce equal percentage of CO_2 emission by 2-5%. This allocation is known as the grandfathering (GF) method (Zhou & Wang, 2016). The GF is economically efficient only if EI of each industry is exactly the same. The economic efficiency is evaluated in terms of the minimum cost in exchange for CO_2 emission reduction. On the other hand, if EI of each industry differs, it can be shown that the equal percentage of CO_2 emission reduction will be uneconomical.

3.2.5.2 The Emission Quota Allocation based on the Equi-marginal Principle

The EIER is represent the marginal external cost of CO_2 emission reduction of individual respective targeted industry in Thailand ETS. Alternatively, the different of EI for each industry, the minimum cost will be achieved by equating EI of all industries. This method is known as the equi-marginal principle. Accordingly, the total CO_2 emission reduction by 2-5% will be unequally shared by industries. The allocation will be any percentage that equates the EI of all industry. The EIER is unique for each industry. The difference can be traced to two factors: the uniqueness of the economic impact, and the quantity of CO_2 emission.

The equi-marginal method for allocate CO_2 emission quotas, to require the conditions of all industries to equate EI, can be defined as Eq.18.

$$EI' = EI_j \tag{19}$$

Where

EI' is the equate EI of all industries

EI_j is the EI of industry *j* in Thailand ETS.

The CO_2 emission quotas that equates the EI of all industry can be solving in terms of the equation in matrix form as follows.

$$AV = C \quad (20)$$

$$V = A^{-1} C \quad (21)$$

Where

V is the column vector of endogenous variables

C is the column vector of constant

A is the square matrix of coefficients.

3.2.6 Computation of Total Economic Cost

The total economic cost of CO_2 quota permits allocations in Thailand ETS can be calculated by aggregate area of the EIER linear of all industries as shown in Figure 3.4 (Jegou & Rubini, 2011)

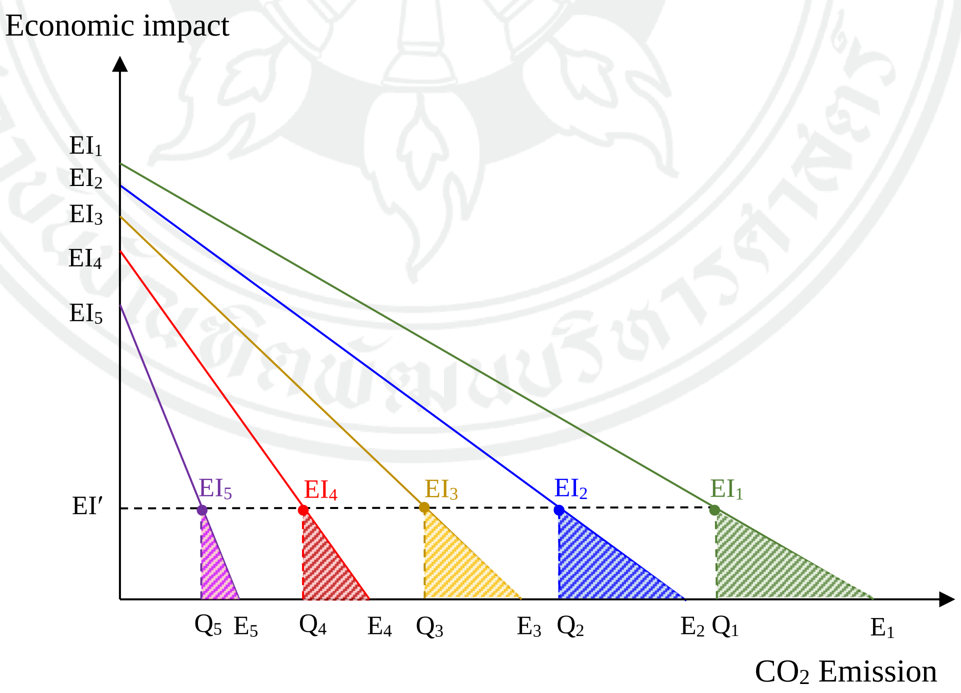


Figure 3.4 The Aggregate Economic Cost of CO_2 Quotas Allocation among Industries in accordance with the Equi-Marginal Principle

The total economic cost for respective industry is the sum of EI for the given quantity of the reduction of CO_2 emission. The total economic cost, denoted by TC_j, for respective industry, which is the sum of economic cost, can be found from the integral of EI function as follows.

$$TC_j = \int_{Q_j}^{E_j} \left(EI_j - a_j E_j\right) \partial E_j \tag{22}$$

The total economic cost for emission allocation in Thailand ETS can be calculated by the sum of TC_j for all industries as shown in Eq.22.

$$\text{Total economic cost} = \sum_{j=1}^{n} TC_j \tag{23}$$

The different total economic cost of CO_2 emission quotas allocated based on the equi-marginal principle and the grandfathering (GF) approach can be investigated by the aggregate area of the EI for all industries that are likely to participate in Thailand ETS.

CHAPTER 4

RESEARCH RESULTS

4.1 Economic Impact of Targeted Industries

Applying the concept of economic impact as the external cost is used to measure the magnitude of the economic linkage at the economy wide scale resulting from the reduction of CO_2 emission of initiating industries in Thailand ETS. The economic impact is computed in terms of the combined strength of forward and backward linkages relevant to industries measured by Leontief's inverse produced by the I-O model. As shown in Table 4-1, The highest forward linkage of electricity sectors was 8.0070, which indicates that the magnitude of the economic impacts over customer chain throughout the economy. The highest backward linkage of aviation industries was 2.2507, which implies that the degree of intermediate inputs uses for other products.

The difference in the value of economic impact in 2010 of the target industries that are likely to participate under Thailand ETS as shown in Table 4-1. Accordingly, the economic impacts measured in terms of the magnitude of the economic linkages for targeted industries. Figure 4-1 presents the ranks of economic impact results. Clearly, electricity sector was the highest economic impact (9.7334), followed by iron and steel industries (5.4200), petrochemical industries (5.0269), aviation (4.5735) and cement industries (4.1612). The results indicate the differential economic impact among the five industries targeted of Thailand ETS. Clearly, the electricity is the highest constant value (9.7334), implying that further emission reduction is much more economic affect for Thailand economy. The limit of CO_2 emission on electricity industry will resulting increase the price of electricity, and the increasing electricity price will raise the price of other commodities. The other commodity price will change according to the changes of electricity price, so the allocation on electricity will indirectly influence on other prices of goods (L. Zhang, Li, & Jia, 2018).

Value-added, which is the sum of labor income, enterprise income including depreciation, and government income, measures the amount of income generated by industry. Output of industry consists of two parts: intermediate factors which comprise goods and services produced by various industries and value-added. The term value-added intensity describes the amount of value-added per unit of output, which suggests the capability of industry to generate income. Figure 4-2 shows that the value-added intensity of cement, aviation, electricity, petrochemical, and iron and steel industries were 0.7688, 0.7002, 0.6926, 0.5715, and 0.4346 respectively. The minimum value-added intensity is iron and steel industries (0.4346) while the maximum value is cement industries (0.7688).

The implementation of the Thailand ETS can be effected change in the economy. CO_2 emission reduction involves the raising cost and price of goods and services of various industries that are interdependent. The cost of emission reduction borne by the interdependence of industries is external to initiating industry. The emission quota allocation in Thailand ETS should consider the economic impact as the external cost of each industries participating in the market. If external cost is taken account, the allocation of emission quota needs to be altered to minimize cost for the whole system.

Table 4.1 The Economic Impacts in 2010 of Targeted Industries under Thailand ETS

Economic Impacts	**Industries**				
	Petrochemical	**Cement**	**Iron and Steel**	**Electricity**	**Aviation**
Forward Linkage [1]	3.3630	2.3265	3.7012	8.0070	2.3227
Backward Linkage [2]	1.6639	1.8347	1.7188	1.7264	2.2507
Economic Impact [3] = [1] + [2]	5.0269	4.1612	5.4200	9.7334	4.5735
Value-added Intensity	0.5715	0.7688	0.4346	0.6926	0.7002

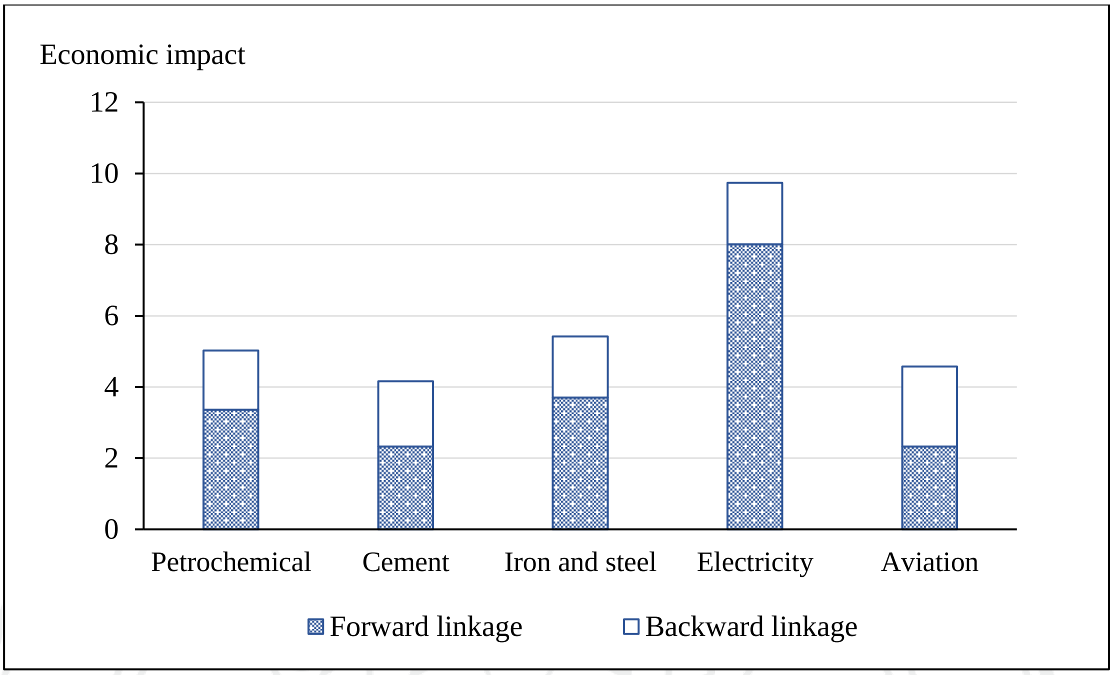


Figure 4.1 The Economic Impacts in 2010 of Targeted Industries under Thailand ETS

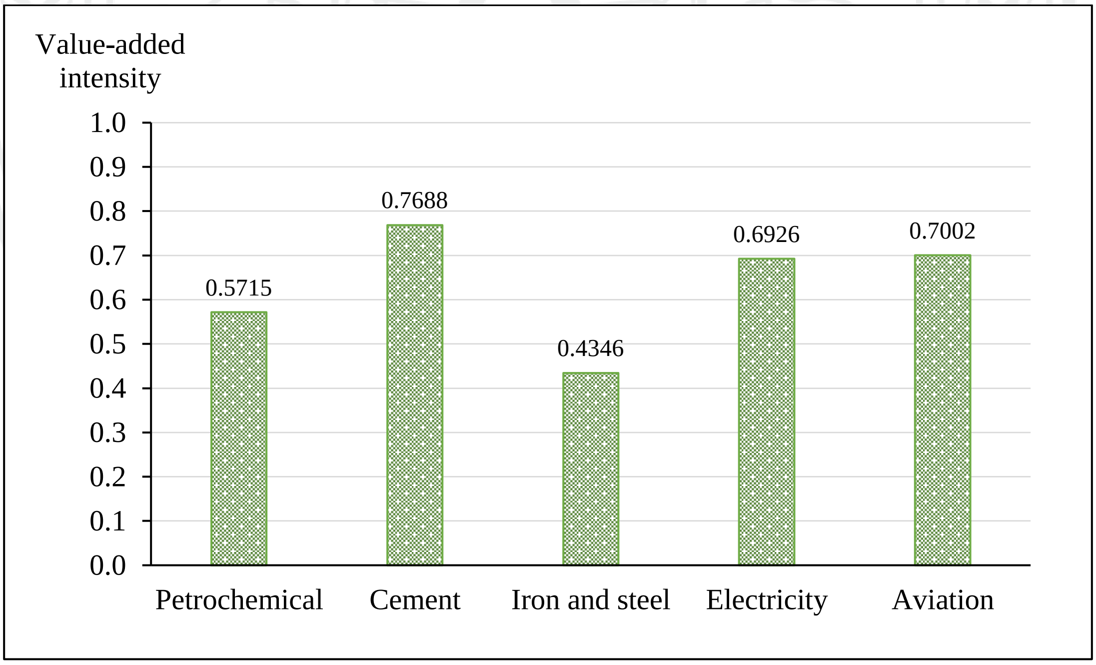


Figure 4.2 The Value-added Intensity in 2010 of Targeted Industries under Thailand ETS

4.2 CO_2 Emission and Emission Intensity

The amount of CO_2 emission of the targeted industries in Thailand ETS focused on direct CO_2 emissions related from fossil fuels combustion. Total CO_2 emission are calculated using the emission factor for GHG inventories following the 2006 IPCC, the result shown in term of CO_2 equivalent (CO_2e). Table 4-2 lists the descriptive statistics of the fossil fuels consumption approximately in different industries. Consequently, the total CO_2 emissions results is shown in Table 4-3. Clearly, the coal consumption is the main source of CO_2 emission followed by petroleum products, and natural gas. Evidently, that more than 77.36% of electricity and 90.40% of cement industries are supplied by coal and its product, this is in agreement with the findings of (H. Liu & Lin, 2017), who founded that more than 70% of electricity in China are produced by coal-fired power.

The computed quantities of total CO_2 emission of the five targeted industries under Thailand ETS was 94.7215 $MtCO_2e$. The amount of CO_2 emission for electricity, cement, petrochemical, aviation and iron and steel were 68.840, 10.841, 10.119, 4.236 and 0.687 $MtCO_2e$, respectively as shown in Figure 4-3. These data results indicated that the share of CO_2 emission for 72.68%, 11.44%, 10.68%, 4.47% and 0.73%, respectively. Figure 4-3 represents the results of the emission intensity (CO_2 emission per unit of output value), the highest emission intensity of electricity and cement industries were 97.543 and 95.286 $tCO_2e/10^6$ baht respectively. Considering, the electricity sector is the main source of CO_2 emissions, where the amounts of energy consumption and CO_2 emissions are approximately 6 times of the levels in the cement industry while nearly the value of emission intensity.

Table 4.2 Fossil fuels consumption in 2010 of Targeted Industries under Thailand ETS

Type of Fossil Fuels	Units	Fossil Fuels Consumption by Sectors				
		Petrochemical	Cement	Iron & Steel	Electricity	Aviation
Coal and its products						
Anthracite	kg	-	-	-	77,686,482	-
Bituminous	kg	-	-	-	2,799,276,697	-
Lignite	kg	-	5,254,531,780	-	43,720,433,101	-
Coke	kg	-	1,512,398	-	-	-
Coal	kg	-	1,566,358,967	8,036,607	-	-
Petroleum oil products						
Diesel	litre	1,162,426	36,826,088	1,117,731	15,213,084	38,094
Fuel oil	litre	450,465,696	241,944,199	129,984,736	1,769,181,145	-
Kerosene	litre	909,192	-	89,243	1,214,659	-
Jet kerosene	litre	-	-	-	-	1,700,394,308
Liquefied Petroleum Gas (LPG)	litre	3,026,661,657	44,178,614	113,487,752	1,544,645,910	-
Natural gas						
Natural gas	kg	1,616,917,238	53,032,286	31,111,524	3,330,254,799	-

Table 4.3 CO_2 Emission from fossil fuels consumption in 2010 of Targeted Industries under Thailand ETS

Type of Fossil Fuels	Units	GHG Emission Factor (kg CO_2e/unit)	CO_2 Emission by Industries ($MtCO_2e$)				
			Petrochemical	Cement	Iron & Steel	Electricity	Aviation
Coal and its products							
Anthracite	kg	3.1014	-	-	-	0.2409	-
Bituminous	kg	2.3440	-	-	-	6.5615	-
Lignite	kg	1.0624	-	5.5824	-	46.4486	-
Coke	kg	2.8377	-	0.0043	-	-	-
Coal	kg	2.6900	-	4.2135	0.0216	-	-
Total of CO_2 from coal and its products combustion			***-***	***9.8002***	***0.0216***	***53.2510***	***-***
Petroleum oil products							
Diesel	litre	2.7080	0.0031	0.0997	0.0030	0.0412	-
Fuel oil	litre	3.0883	1.3912	0.7472	0.4014	5.4638	-
Kerosene	litre	2.4777	0.0023	-	0.0002	0.0030	-
Liquefied Petroleum Gas (LPG)	litre	1.6812	5.0884	0.0743	0.1908	2.5969	-
Jet kerosene	litre	2.4910	-	-	-	-	4.2357
Total of CO_2 from petroleum oil products combustion			***6.4850***	***0.9212***	***0.5955***	***8.1048***	***4.2357***
Natural gas							
Natural gas	kg	2.2472	3.6335	0.1192	0.0699	7.4837	-
Total of CO_2 from natural gas combustion			***3.6335***	***0.1192***	***0.0699***	***7.4837***	***-***
Total CO_2 emission			***10.1185***	***10.8406***	***0.6870***	***68.8396***	***4.2358***

Table 4.4 Percentage Share of CO_2 Emission and Emission Intensity in 2010 of Targeted Industries under Thailand ETS

Emission	Units	Industries				
		Petrochemical	**Cement**	**Iron and Steel**	**Electricity**	**Aviation**
CO_2 Emission [1]	tCO_2e	10,118,534	10,840,580	687,008	68,839,606	4,235,785
Percentage Share of CO_2 Emission	%	10.68	11.44	0.73	72.68	4.47
Output Value [2]	10^6 Baht	383,699	113,768	137,184	705,732	267,049
CO_2 Emission Intensity [3] = [1] / [2]	tCO_2e /10^6 Baht	26.3710	95.2863	5.0079	97.5434	15.8614

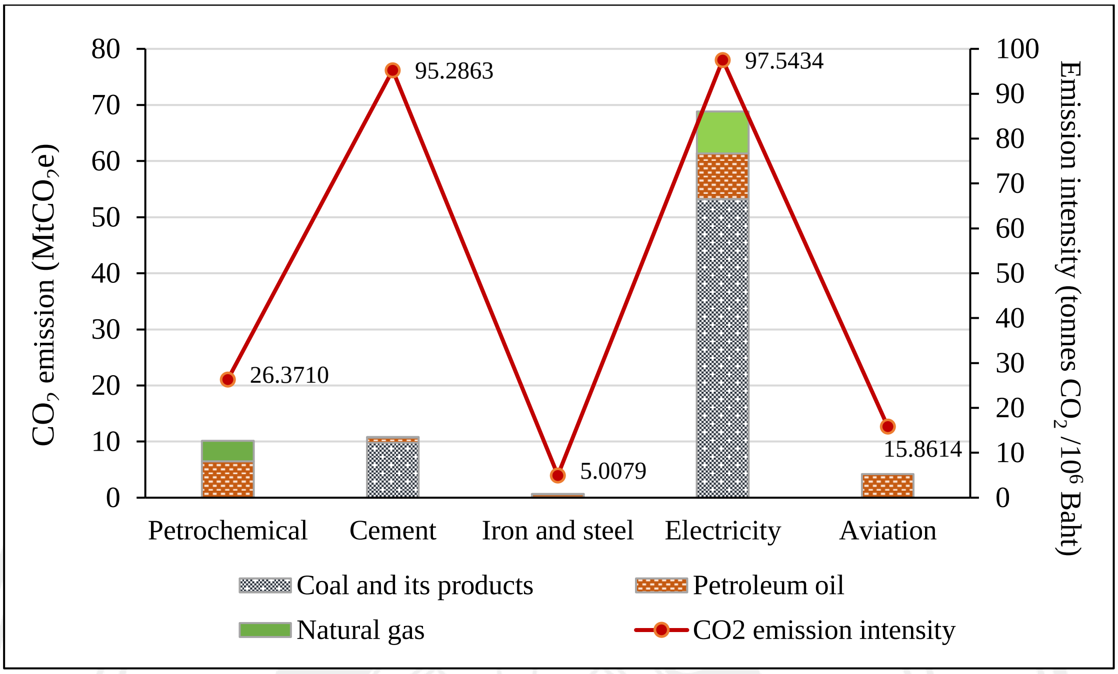


Figure 4.3 CO_2 emissions and emission intensity in 2010 of targeted industries under Thailand ETS

4.3 Simulation of EIERs for Targeted Industries

The Economic Impact – Emission Ratio (EIER) is constructed as the change in the economic impact per additional unit of reduction of CO_2 emission. This is symbolically denoted by $-\Delta EI/\Delta E$. The magnitude of $\Delta EIER$ is measured on the vertical axis, and ΔE on the horizontal axis. The larger is the reduction of CO_2 emission, measured on the horizontal axis, the larger magnitude the EIER will be, as measured on the vertical axis. The difference of EIERs for industries is explained by their difference in the magnitude of the economic impact and the quantity of CO_2 emission. Figure 4-4 depicts the EIERs for five targeted industries and the EIERs results is expressed as.

Petrochemical industries	$EI_1 = 5.027 - 0.50E_1$
Cement industries	$EI_2 = 4.161 - 0.38E_2$
Iron and steel industries	$EI_3 = 5.420 - 7.89E_3$
Electricity	$EI_4 = 9.733 - 0.14E_4$
Aviation	$EI_5 = 4.573 - 1.08E_5$

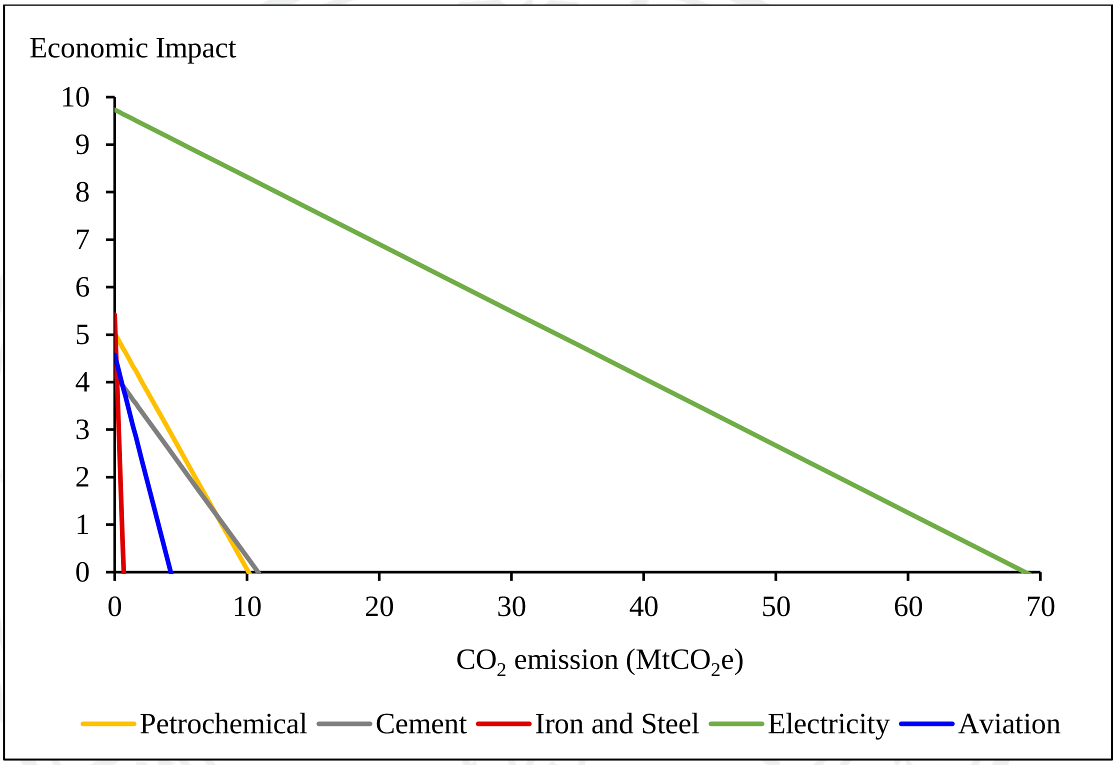


Figure 4.4 The EIERs for five targeted industries under Thailand ETS

The difference indicates that EIERs of five targeted industries under Thailand ETS in different vary considerably. Thus, for the sake of minimizing the economic cost of emission allocation, it is necessary to explore CO_2 emission quota allocation among the industries according to their EIERs.

4.4 Sectoral Emission Quotas Allocations

4.4.1 The Proportional Allocation based on Grandfathering (GF) Method

Grandfathering (GF) or fixed allocation is allocated for emission quotas in proportion based on the historical CO_2 emissions percentage as a reference base year. The cap setting target of Thailand V-ETS was 2% GHG reduction based on the carbon intensity compared with 2012-2013 level. To simulate the cap setting of this study has construct four scenarios (2-5% CO_2 emission reduction based on the year 2010) for seeking which is a proportional of allowance allocation for industries on Thailand ETS.

In term of emission quotas allocation, according to the cap setting target in the four scenarios, the total allowances under the scenario I (2% CO_2 reduction target), scenario II (3% CO_2 reduction target), scenario III (4% CO_2 reduction target) and scenario IV (5% CO_2 reduction target) are 92.8271, 91.8799, 90.9327 and 89.9854 $MtCO_2e$ respectively. Accordingly, each industry is obliged to reduce equal percentage of CO_2 emission based on the historical in a reference base year as shown in Figure 4-5.

4.4.2 The Proportional Allocation based on Equi-marginal Method

For the computation of CO_2 emission quotas based on the equi-marginal, the EIERs equation for five targeted industries on Thailand ETS and the total allowances as follows.

Petrochemical industries	$EI_1 = 5.027 - 0.50E_1$
Cement industries	$EI_2 = 4.161 - 0.38E_2$
Iron and steel industries	$EI_3 = 5.420 - 7.89E_3$
Electricity	$EI_4 = 9.733 - 0.14E_4$
Aviation	$EI_5 = 4.573 - 1.08E_5$
Total CO_2 emission targeted	$E_{target} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$

Table 4.5 The Emission Quota Allocation based on the Grandfathering (GF) Method for 2-5% CO_2 reduction target

Scenario	E_{target} ($MtCO_2e$)	CO_2 Emission Quota Allocation ($MtCO_2e$) based on GF by Industries					
		Petrochemical (Q_{1GF})	Cement (Q_{2GF})	Iron and steel (Q_{3GF})	Electricity (Q_{4GF})	Aviation (Q_{5GF})	Total
CO_2 Emission in 2010 (Base Year)	-	10.1185	10.8406	0.6870	68.8396	4.2358	94.7215
Scenario I (2% CO_2 reduction target)	92.8271	9.9162	10.6238	0.6733	67.4628	4.1511	92.8271
Scenario II (3% CO_2 reduction target)	91.8799	9.8150	10.5154	0.6664	66.7744	4.1087	91.8799
Scenario III (4% CO_2 reduction target)	90.9327	9.7138	10.4070	0.6595	66.0860	4.0664	90.9327
Scenario IV (5% CO_2 reduction target)	89.9854	9.6126	10.2986	0.6527	65.3976	4.0240	89.9854

As described equation earlier is arranged in table format as shown in Table 4-6.

Table 4.6 Equations of EIERs for five targeted industries on Thailand ETS

EI	Q_1	Q_2	Q_3	Q_4	Q_5	C
1	0.50	0	0	0	0	5.027
1	0	0.38	0	0	0	4.161
1	0	0	7.89	0	0	5.420
1	0	0	0	0.14	0	9.733
1	0	0	0	0	1.08	4.573
0	1	1	1	1	1	E_{target}

As an example, the scenario IV (5% CO_2 reduction target) when E_{target} takes the value of 89.99 $MtCO_2e$. The parameters in Table 4-6 can be arranged in matrix form of $AV = C$ as follows.

$$\begin{bmatrix} 1 & 0.50 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0.38 & 0 & 0 & 0 \\ 1 & 0 & 0 & 7.89 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0.14 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1.08 \\ 0 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} \mathrm{EI} \\ Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \end{bmatrix} = \begin{bmatrix} 5.027 \\ 4.161 \\ 5.420 \\ 9.733 \\ 4.573 \\ 89.99 \end{bmatrix}$$

The matrix can be transformed to solve for $V = A^{-1}C$ as shown below.

$$\begin{bmatrix} \mathrm{EI} \\ Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \end{bmatrix} = \begin{bmatrix} 1 & 0.50 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0.38 & 0 & 0 & 0 \\ 1 & 0 & 0 & 7.89 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0.14 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1.08 \\ 0 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} 5.027 \\ 4.161 \\ 5.420 \\ 9.733 \\ 4.573 \\ 89.99 \end{bmatrix}$$

The solutions for $V = A^{-1}C$ are found as shown below.

$$\begin{bmatrix} \mathrm{EI} \\ \mathrm{Q}_1 \\ \mathrm{Q}_2 \\ \mathrm{Q}_3 \\ \mathrm{Q}_4 \\ \mathrm{Q}_5 \end{bmatrix} = \begin{bmatrix} 0.16 & 0.20 & 0.01 & 0.55 & 0.07 & -0.08 \\ 1.70 & -0.41 & -0.02 & -1.12 & -0.15 & 0.16 \\ -0.41 & 2.07 & -0.03 & -1.45 & -0.19 & 0.20 \\ -0.02 & -0.03 & 0.13 & -0.07 & -0.01 & 0.01 \\ -1.12 & -1.45 & -0.07 & 3.15 & -0.51 & 0.56 \\ -0.15 & -0.19 & -0.01 & -0.51 & 0.86 & 0.07 \end{bmatrix} \begin{bmatrix} 5.027 \\ 4.161 \\ 5.420 \\ 9.733 \\ 4.573 \\ 89.99 \end{bmatrix}$$

The value for V is found as follows.

$$\begin{bmatrix} EI \\ Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \end{bmatrix} = \begin{bmatrix} 0.37 \\ 9.37 \\ 9.87 \\ 0.64 \\ 66.21 \\ 3.89 \end{bmatrix}$$

As described earlier, when E_{target}, is determined for Thailand ETS to achieve 2-5% CO_2 reduction target, the solutions result for variables are presented in Table 4-7. Table 4-7 presented the results of economic impact (EI_j) and the proportion allocation of CO_2 emission quota (Q_j) in unit of $MtCO_2e$ based on equi-marginal principle, for petrochemical, cement, iron and steel, electricity, and aviation industries respectively.

Table 4.7 The Solutions Based on the Equi-Marginal for 2-5% CO_2 Reduction

Scenario	E_{target} ($MtCO_2e$)	CO_2 Emission Quota Allocation ($MtCO_2e$) based on Equi-Marginal by Industries					
		Petrochemical (Q_{1EQ})	Cement (Q_{2EQ})	Iron and steel (Q_{3EQ})	Electricity (Q_{4EQ})	Aviation (Q_{5EQ})	Total
CO_2 Emission in 2010 (Base Year)	-	10.1185	10.8406	0.6870	68.8396	4.2358	94.7215
Scenario I (2% CO_2 reduction target)	92.8271	9.8193	10.4533	0.6399	66.2111	3.8916	92.8271
Scenario II (3% CO_2 reduction target)	91.8799	9.6697	10.2597	0.6493	66.7368	3.9604	91.8799
Scenario III (4% CO_2 reduction target)	90.9327	9.5201	10.0660	0.6587	67.2625	4.0293	90.9327
Scenario IV (5% CO_2 reduction target)	89.9854	9.3705	9.8724	0.6682	67.7882	4.0981	89.9854

4.5 Comparative analysis of Emission Quotas Allocation and Economic Impact

The results allocation of the grandfathering and equi-marginal methods including CO_2 emission quotas allowance and economic impact of each industry (EI_j) are shown in Table 4-8. The CO_2 emission quotas for respective industry using the equi-marginal method, the computed quantity using the differs in percentage of the allocation. Accordingly, the cap setting of 2-5% CO_2 emission reduction under Thailand ETS will be allocated to respective industry in any percentage to equate the EI. Thus, for seeking the minimize of nationwide economic cost, it is necessary to explore CO_2 emission quota allocation among the industries according to their EIERs.

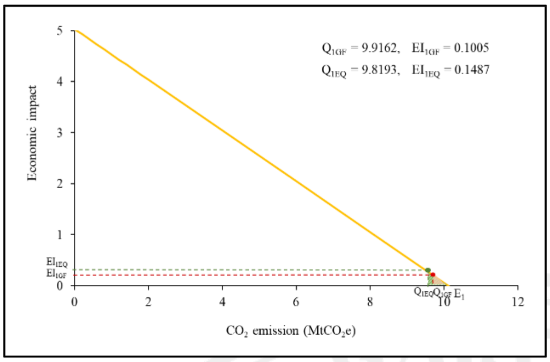
Table 4-8 presents the comparison of CO_2 emission quotas for the industries under two allocation mechanisms. Clearly, the equi-marginal method allocates more quota for the electricity sector and fewer for other 4 sectors. In the case of equi-marginal, CO_2 emission allowances of the electricity sector are much higher than the grandfathering method. As mentioned earlier, we simplify the setting of the total CO_2 emission quotas in Thailand ETS and take the sum of quotas for electricity is higher than proportion based on historical CO_2 emissions percentage as a reference base year, whereas the quota allowances for other industries including petrochemical, cement, iron and steel, and aviation are allocated in lower than their proportion. The result of the equi-marginal allocation indicated that the electricity sector should be allocated higher carbon emissions quota, which receives the majority of the allowances under Thailand ETS. This result corroborates the conclusion of R. Li and Tang (2016) and Yang and Lin (2016), who concluded that the power industry is an important sector for allocating carbon emission quotas.

As shown in Table 4-8, the differences of EI_j under two allocation mechanism in five targeted industries. The grandfathering method, the result shown that EI for petrochemical, cement, iron and steel, electricity and aviation industries in different vary considerably. In contrast with the equi-marginal method, the results give all industries are equal EI_j. The comparison of CO_2 emission quotas and EI_j under two allocation methods of targeted industries in four scenarios are presented in Figure 4-5 to Figure 4-8

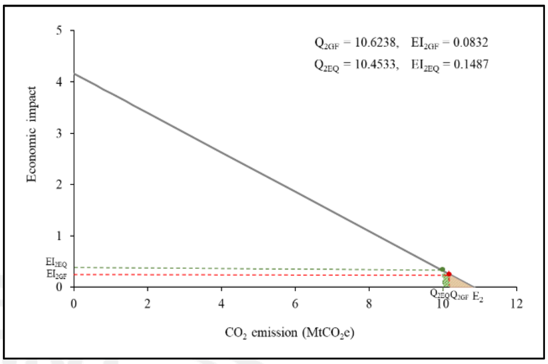
Table 4.8 Different CO_2 Quotas Allocation and Economic Impact of Industries according to Grandfathering and Equi-marginal Allocation Methods by 2-5 % CO_2 Reduction Target

Characteristics	**Allocation method**	**Industries**					**Total**
		Petrochemical	**Cement**	**Iron and steel**	**Electricity**	**Aviation**	
Scenario I (2% CO_2 reduction target)							
CO_2 Emission quotas ($MtCO_2e$)	Grandfathering	9.9162	10.6238	0.6733	67.4628	4.1511	92.8271
	Equi-marginal	9.8193	10.4533	0.6682	67.7882	4.0981	92.8271
Economic Impact (EI_j)	Grandfathering	0.1005	0.0832	0.1084	0.1947	0.0915	-
	Equi-marginal	0.1487	0.1487	0.1487	0.1487	0.1487	-
Scenario II (3% CO_2 reduction target)							
CO_2 Emission quotas ($MtCO_2e$)	Grandfathering	9.8150	10.5154	0.6664	66.7744	4.1087	91.8799
	Equi-marginal	9.6697	10.2597	0.6587	67.2625	4.0293	91.8799
Economic Impact (EI_j)	Grandfathering	0.1508	0.1248	0.1626	0.2920	0.1372	-
	Equi-marginal	0.2230	0.2230	0.2230	0.2230	0.2230	-
Scenario III (4% CO_2 reduction target)							
CO_2 Emission quotas ($MtCO_2e$)	Grandfathering	9.7138	10.4070	0.6595	66.0860	4.0664	90.9327
	Equi-marginal	9.5201	10.0660	0.6493	66.7368	3.9604	90.9327
Economic Impact (EI_j)	Grandfathering	0.2011	0.1664	0.2168	0.3893	0.1829	-
	Equi-marginal	0.2973	0.2973	0.2973	0.2973	0.2973	-

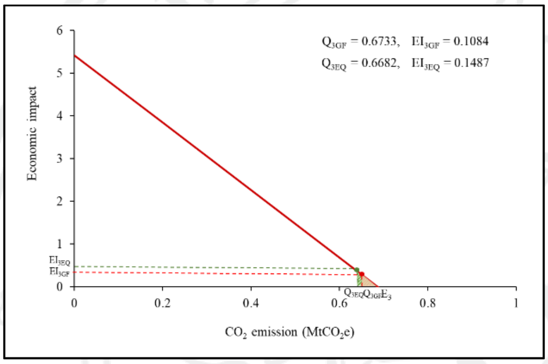
Characteristics	Allocation method	Industries					Total
		Petrochemical	Cement	Iron and steel	Electricity	Aviation	
Scenario IV (5% CO_2 reduction target)							
CO_2 Emission quotas ($MtCO_2e$)	Grandfathering	9.6126	10.2986	0.6527	65.3976	4.0240	89.9854
	Equi-marginal	9.3705	9.8724	0.6399	66.2111	3.8916	89.9854
Economic Impact (EI_j)	Grandfathering	0.2513	0.2081	0.2710	0.4867	0.2287	-
	Equi-marginal	0.3716	0.3716	0.3716	0.3716	0.3716	-



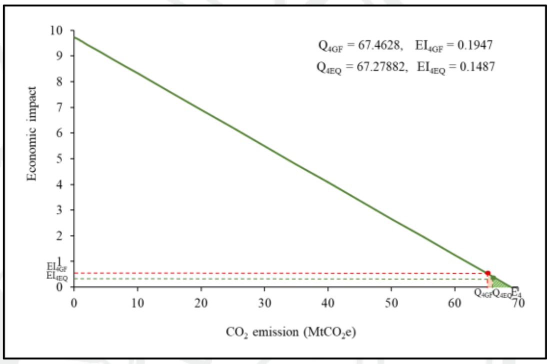
(A) Petrochemical



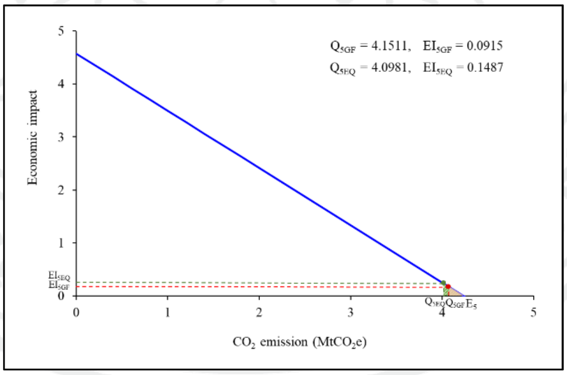
(B) Cement



(C) Iron and Steel

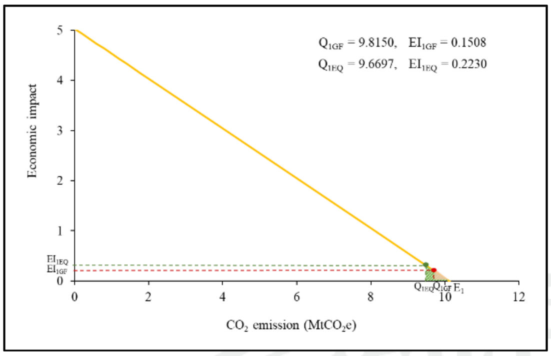


(D) Electricity

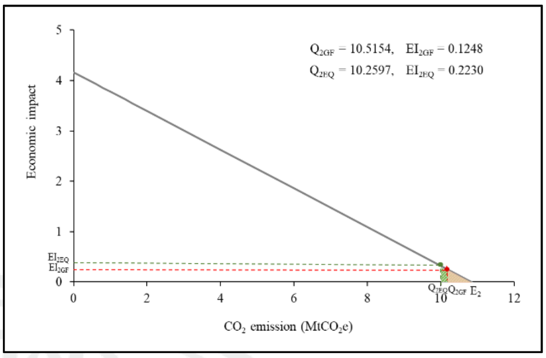


(E) Aviation

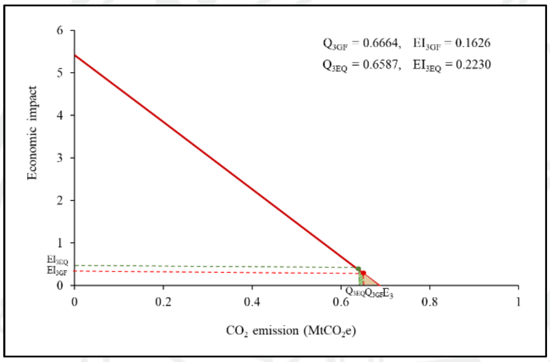
Figure 4.5 Carbon Quotas Allocation and Economic Impact of Industries with 2% CO_2 Reduction Target



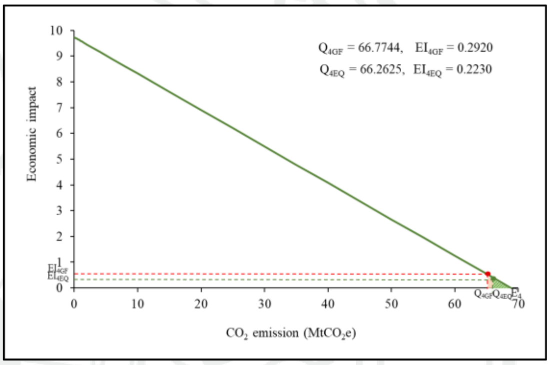
(A) Petrochemical



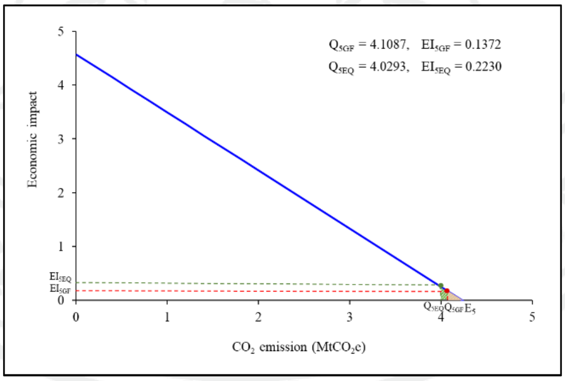
(B) Cement



(C) Iron and Steel

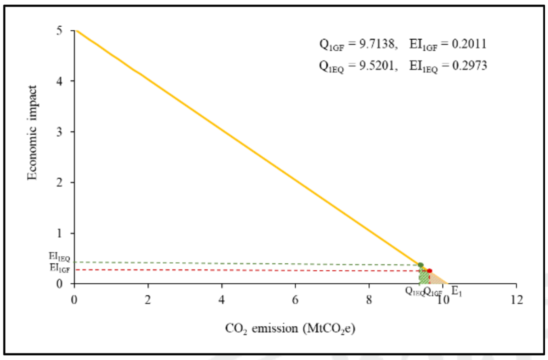


(D) Electricity

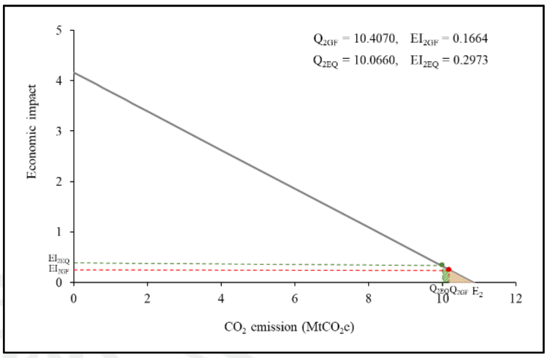


(E) Aviation

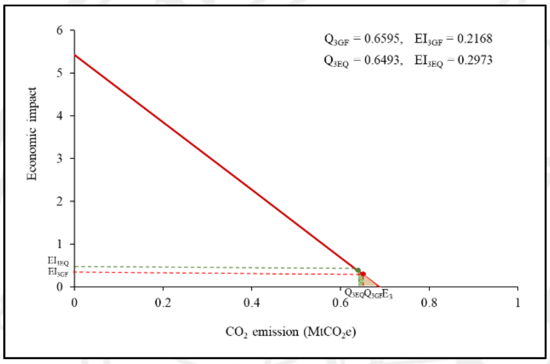
Figure 4.6 Carbon Quotas Allocation and Economic Impact of Industries with 3% CO_2 Reduction Target



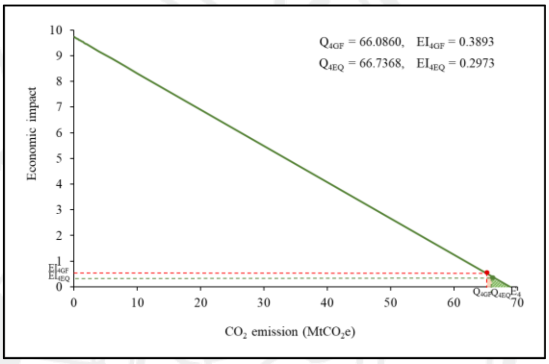
(A) Petrochemical



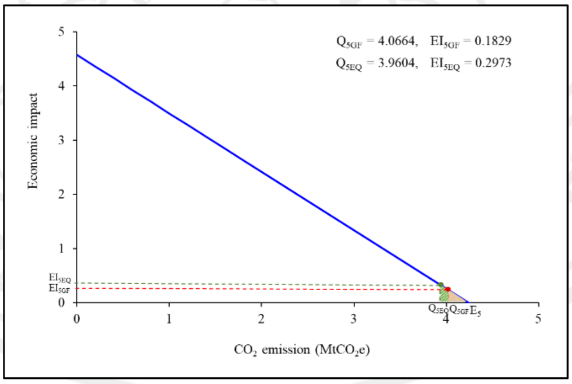
(B) Cement



(C) Iron and Steel

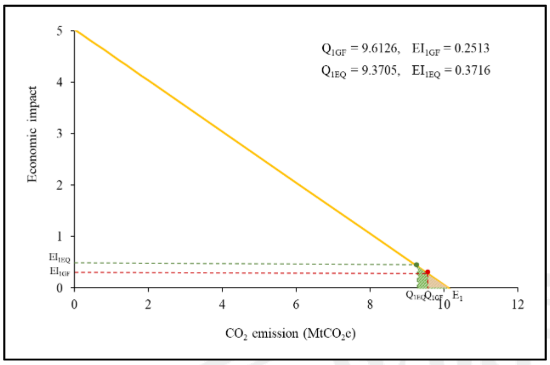


(D) Electricity

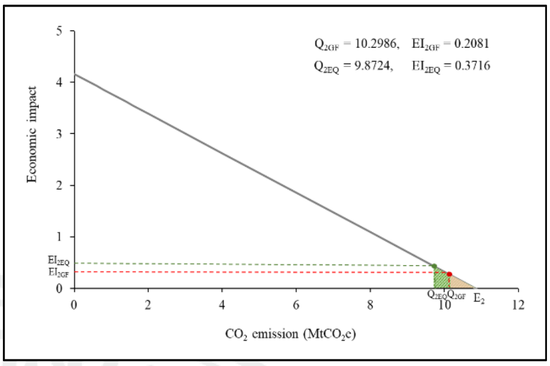


(E) Aviation

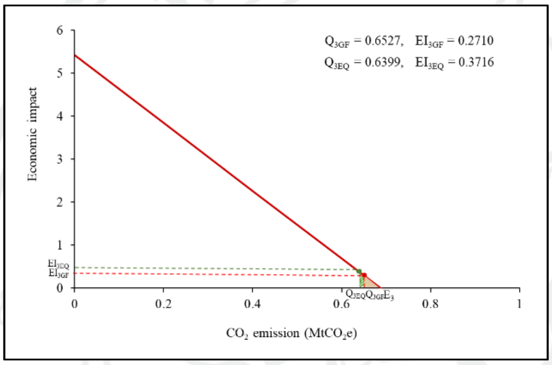
Figure 4.7 Carbon Quotas Allocation and Economic Impact of Industries with 4% CO_2 Reduction Target



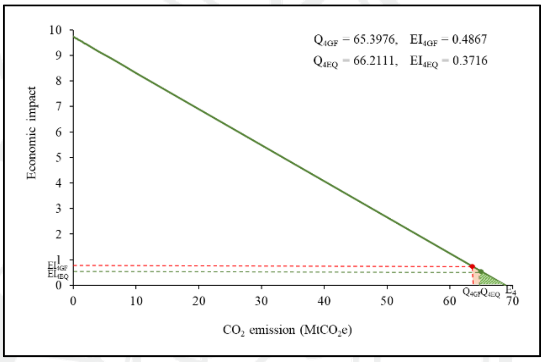
(A) Petrochemical



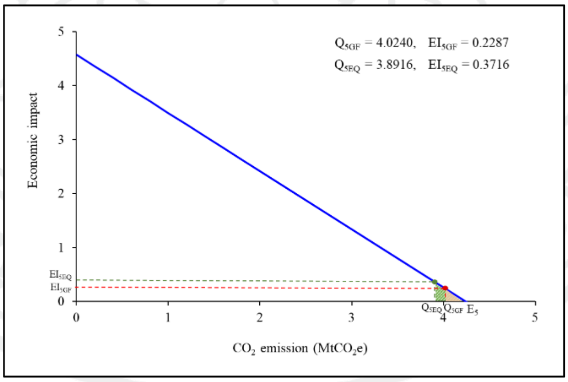
(B) Cement



(C) Iron and Steel



(D) Electricity



(E) Aviation

Figure 4.8 Carbon Quotas Allocation and Economic Impact of Industries with 5% CO_2 Reduction Target

4.6 Different of Total Economic Cost

In terms of the total economic cost of CO_2 quota permits allocations in Thailand ETS is the area under the EIERs for the given quantity of the reduction of CO_2 emission. The area is found by the integral of EI for the given quantity of the CO_2 reduction, the total economic cost for each industry can be calculated by aggregate area of the EIER linear of all industries. The total economic cost is found by the sum of economic cost of all industry as shown in Table 4-9. The different total economic cost of CO_2 emission quotas allocated based on the equi-marginal and grandfathering method can be investigated by the aggregate area of the EI_j for all industries that are likely to participate in Thailand ETS.

According to the 2-5 % CO_2 reduction target in the scenarios setting, the total economic cost based on the grandfathering allocation under I, II, III and IV scenarios are 0.1578, 0.3551, 0.6313 and 0.9864 respectively, whereas the total economic cost under equi-marginal are 0.1408, 0.3168, 0.5632 and 0.8801 respectively. Figure 4-9 further depicts the differences of total economic cost under two allocation mechanism in five targeted industries. In terms of the different total economic cost, clearly under the scenarios setting indicated that the total economic cost under equi-marginal lower than grandfathering allocation method by 0.017, 0.0383, 0.0681 and 0.1063 respectively. The results shown that the total economic cost will increase when more stringent CO_2 reduction target are applied.

As shown in Table 4-9, the electricity sector receives the majority impact of total economic cost. The change in electricity industry would significantly exceed the other industries. The equi-marginal allocated results in less economic cost of the electricity than grandfathering method, thus contributing to the lower overall of total economic cost.

Table 4.9 Different the Total Economic Cost of Industries according to Grandfathering and Equi-marginal Allocation by 2-5 % CO_2 Reduction Target

Allocation Method	**Economic Cost by Industries**					**Total**
	Petrochemical	**Cement**	**Iron and steel**	**Electricity**	**Aviation**	
Scenario I (2% CO_2 reduction target)						
Grandfathering [1]	0.0102	0.0090	0.0007	0.1340	0.0039	0.1578
Equi-marginal [2]	0.0222	0.0288	0.0014	0.0781	0.0102	0.1408
Different of total economic cost [2]-[1] (The Equi-marginal compared to Grandfathering)	+0.0120	+0.0198	+0.0007	-0.0559	+0.0063	-0.0170
Scenario II (3% CO_2 reduction target)						
Grandfathering [1]	0.0229	0.0203	0.0017	0.3015	0.0087	0.3551
Equi-marginal [2]	0.0500	0.0648	0.0032	0.1758	0.0230	0.3168
Different of total economic cost [2]-[1] (The Equi-marginal compared to Grandfathering)	+0.0271	+0.0445	+0.0015	-0.1257	+0.0143	-0.0383
Scenario III (4% CO_2 reduction target)						
Grandfathering [1]	0.0407	0.0361	0.0030	0.5360	0.0155	0.6313
Equi-marginal [2]	0.0890	0.1151	0.0056	0.3126	0.0409	0.5632
Different of total economic cost [2]-[1] (The Equi-marginal compared to Grandfathering)	+0.0483	+0.0790	+0.0026	-0.2234	+0.0254	-0.0681

Allocation Method	Economic Cost by Industries					Total
	Petrochemical	Cement	Iron and steel	Electricity	Aviation	
Scenario IV (5% CO_2 reduction target)						
Grandfathering [1]	0.0636	0.0564	0.0047	0.8376	0.0242	0.9864
Equi-marginal [2]	0.1390	0.1799	0.0088	0.4884	0.0640	0.8801
Different of total economic cost [2]-[1] (The Equi-marginal compared to Grandfathering)	+0.0754	+0.1235	+0.0041	-0.3492	+0.0398	-0.1063

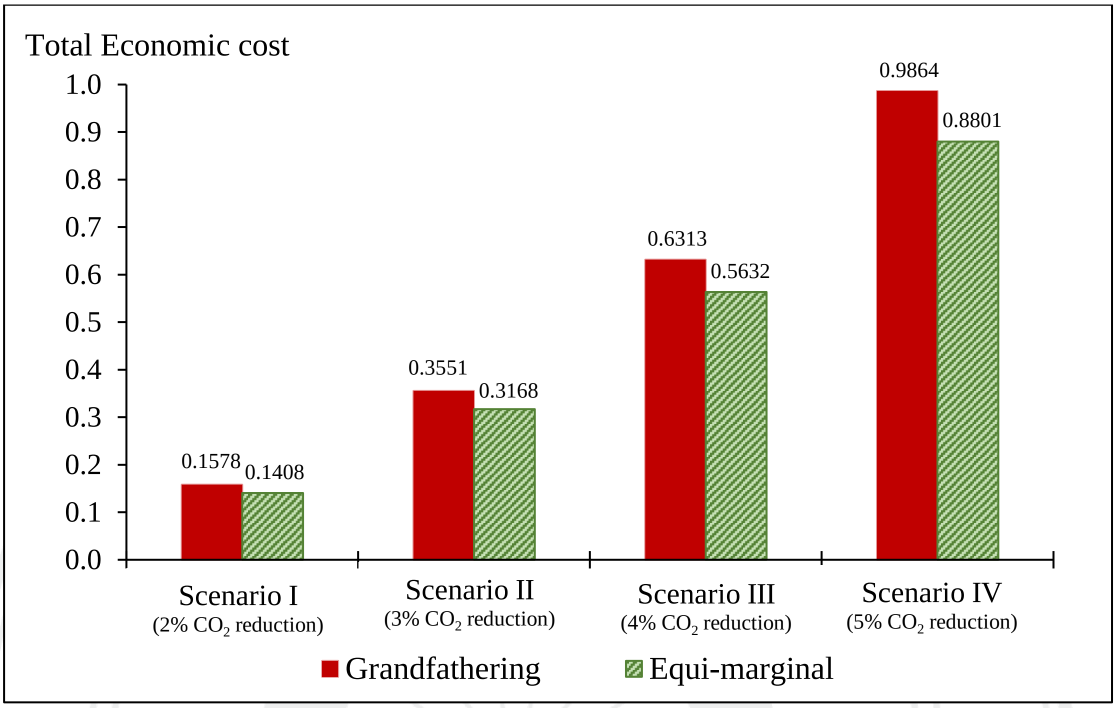


Figure 4.9 Comparison of the Total Economic Cost under Grandfathering and Equi-marginal Methods

4.7 Optimal Emission Quota Allocation for Industries in Thailand ETS

Under the scenarios where CO_2 caps exist, two allocation mechanism results in different total economic cost. The grandfathering is the simplest quota allocation to equally impose a uniform reduction target for each industry. Based on the equi-marginal principle, the results can obtain the optimal carbon emission quota allocation by solving the equations above in 4.4.2, which are equal to the economic impact of all industries (EI′) beyond autonomous contribution carbon emission quotas among industries.

Table 4-10 presents the different of emission quotas contribution ratio and cost saving under two allocation methods in five targeted industries, the results shown that the equi-marginal allocation gives all industries are equalized EI_j, therefore the economic efficiency is automatically achieved, which can be investigated by the sum of cost of all industries is minimized.

The optimal carbon emission quota allocation refers to the least total economic cost of the reduction of CO_2 emission. The comparison of the computed total economic cost and the emission quota under the equi-marginal and the grandfathering method as shown in Table 4-10. Based on Table 4-10, the results shown that the allocation with grandfathering is inefficiency because the total economic cost of all industries is not necessarily at minimum cost, this is in agreement with the findings of Mu, Li, Li, Xue, and Li (2016). The optimal allocation of carbon emission quotas can be managed by equi-marginal principle to equate EI_j of industries to ensure minimum economic cost and achieved the economic efficiency of allocation. It is clearly evident from Table 4-10, a compare the outcomes under the two allocation methods, the results indicated that the total economic cost of all industries in Thailand ETS under equi-marginal is lower than grandfathering allocation method. Overall, approximately 10.78% can be saved by implementing the optimal quota allocation.

Figure 4-10 presents the different of CO_2 quotas contribution ratio under two allocation methods. The shares of the computed optimal initial carbon emission quotas for petrochemicals, cement, iron and steel, electricity, and aviation industries are 10.4133%, 10.9711%, 0.7111%, 73.5798% and 4.3247%, respectively. The ratios of carbon emission quotas by grandfathering method for petrochemicals, cement, iron and steel, and aviation sectors are bigger than those of their optimal CO_2 emissions, while the ratios of carbon emission quotas for electricity is smaller than the optimal CO_2 emissions.

The optimal allocation can be achieved by equi-marginal method, the electricity sector given with larger quota and other four sectors with fewer quotas so that EI_j are equal, the least cost is accomplished. The results of the optimal allocation for targeted industries are present in Table 4-10. Clearly, the emission quotas for electricity industries under the optimal allocation are 0.3254, 0.4881, 0.6508 and 0.8135 $MtCO_2e$ for I, II, III and IV scenarios respectively. Moreover, the difference between emission quotas contribution ratio of electricity for fixed allocation method less than under the optimal carbon emissions quota allocation approximately 0.904 %.

Inversely, the other four industries will have to reduce more CO_2 emissions under the optimal allocation mechanism. This result agrees with the study by Ma, Ren, Zhang, and Sharp (2018), which suggest that the power generation has significantly positive influence on the allocation of carbon emission quotas. The results of Yu et al. (2018) shown that the power generation sector receive the majority of the allowances under Shanghai's carbon emissions trading scheme. The change in allowance allocation on electricity industry may significantly affect economy and environment, this is in agreement with the findings of L. Zhang et al. (2018), who concluded that the allowance allocation of electricity industry can hardly affect GDP and CO_2 emissions.

Table 4.10 Different of CO_2 Emission Quotas Contribution Ratio and Cost Saving of Industries according to Grandfathering and Equi-marginal Allocation Methods

	Industries					Total
	Petrochemical	**Cement**	**Iron and Steel**	**Electricity**	**Aviation**	
Carbon Quotas Contribution Ratio (%)						
Grandfathering [1]	10.6824	11.4447	0.7253	72.6758	4.4718	100.00
Equi-marginal [2]	10.4133	10.9711	0.7111	73.5798	4.3247	100.00
Different of Quotas Contribution Ratio (%)						
The Equi-marginal compared to Grandfathering [2] – [1]	-0.2691	-0.4736	-0.0142	+0.904	-0.1471	-
Scenario I (2% CO_2 reduction target)						
Total Economic Cost						
Grandfathering [3]	0.0102	0.0090	0.0007	0.1340	0.0039	0.1578
Equi-marginal [4]	0.0222	0.0288	0.0014	0.0781	0.0102	0.1408
Cost Saving (%)						
[5] = [[3] – [4]] * 100/[3]						10.78
Different of CO_2 Quotas Allocation ($MtCO_2e$)						
The Equi-marginal compared to Grandfathering	-0.0969	-0.1705	-0.0051	+0.3254	-0.0530	-
Scenario II (3% CO_2 reduction target)						
Total Economic Cost						
Grandfathering [3]	0.0229	0.0203	0.0017	0.3015	0.0087	0.3551
Equi-marginal [4]	0.0500	0.0648	0.0032	0.1758	0.0230	0.3168

	Industries					Total
	Petrochemical	Cement	Iron and Steel	Electricity	Aviation	
Cost Saving (%)						
[5] = [[3] – [4]] * 100/[3]						10.78
Different of CO_2 Quotas Allocation ($MtCO_2e$)						
The Equi-marginal compared to Grandfathering	-0.1453	-0.2557	-0.0077	+0.4881	-0.0795	-
Scenario III (4% CO_2 reduction target)						
Total Economic Cost						
Grandfathering [3]	0.0407	0.0361	0.0030	0.5360	0.0155	0.6313
Equi-marginal [4]	0.0890	0.1151	0.0056	0.3126	0.0409	0.5632
Cost Saving (%)						
[5] = [[3] – [4]] * 100/[3]						10.78
Different of CO_2 Quotas Allocation ($MtCO_2e$)						
The Equi-marginal compared to Grandfathering	-0.1937	-0.3409	-0.0102	+0.6508	-0.1059	-
Scenario IV (5% CO_2 reduction target)						
Total Economic Cost						
Grandfathering [3]	0.0636	0.0564	0.0047	0.8376	0.0242	0.9864
Equi-marginal [4]	0.1390	0.1799	0.0088	0.4884	0.0640	0.8801
Cost Saving (%)						
[5] = [[3] – [4]] * 100/[3]						10.78
Different of CO_2 Quotas Allocation ($MtCO_2e$)						
The Equi-marginal compared to Grandfathering	-0.2422	-0.4262	-0.0128	+0.8135	-0.1324	-

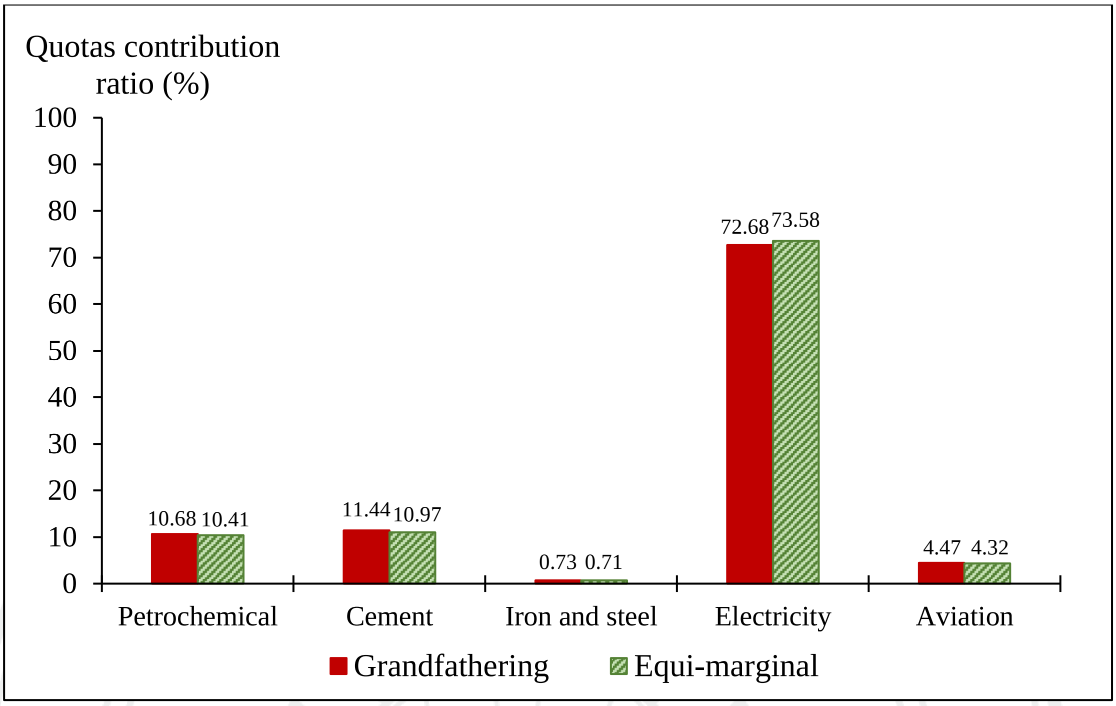


Figure 4.10 Comparison of CO_2 Emission Quotas Contribution Ratio under Grandfathering and Equi-marginal Allocation Methods

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

The implementation of the Thailand ETS can be expected to significant effect change in the economy. The cost of CO_2 emission reduction borne by the different interdependence of industries is external to initiating industry. If external cost is taken account, the allocation of carbon emission quota needs to be altered to minimize cost for the whole system. This study applying the concept of economic impact as the external cost is used to measure the magnitude of the Thailand economic impacts resulting from the CO_2 emission reduction of initiating industries in Thailand ETS. The economic impact is computed in terms of the combined strength of forward and backward linkages relevant to industries measured by Leontief's inverse produced by the I-O model.

The results allocation of the equi-marginal methods of this study to allocated optimal CO_2 emission quotas among industries in Thailand ETS based on the fairness and efficiency principles, and several main conclusions are obtained as follows.

Firstly, the difference of Economic Impact – Emission Ratio (EIER) for industries in Thailand ETS is explained by their difference in the magnitude of the economic impact per additional unit of reduction of CO_2 emission. The electricity sector was the highest economic impact ($EI_4 = 9.733 - 0.14E_4$), followed by iron and steel industries ($EI_3 = 5.420 - 7.89E_3$), petrochemical industries ($EI_1 = 5.027 - 0.50E_1$), aviation ($EI_5 = 4.573 - 1.08E_5$) and cement industries ($EI_2 = 4.161 - 0.38E_2$). In the case of Thailand ETS, the electricity is much more economic affect for Thailand economy, indicating that the prioritized sectors for allocated emission quota, so the electricity will directly influence on other prices of commodities and services.

Secondly, the equi-marginal method is able to allocate CO_2 emission quotas fairly and efficiently. The equi-marginal allocation gives all industries in Thailand ETS are equalized economic impact (EI′), therefore the economic efficiency is automatically achieved. In contrast with the grandfathering allocation, EI_j of industries in different vary considerably. The result of the equi-marginal method indicated that the electricity sector is the most carbon emission quotas allocation, the quotas of electricity will get the higher than proportion based on historical CO_2 emissions percentage as a reference base year, while the quota allowances for other industries including petrochemical, cement, iron and steel, and aviation are allocated in lower than their proportion. The result of total economic cost of CO_2 quota permits allocations according to the cap setting 2-5 % CO_2 reduction target in the scenarios setting in Thailand ETS based on the equi-marginal lower than grandfathering allocation method by 0.017, 0.0383, 0.0681 and 0.1063 respectively. The results evidently shown that the equi-marginal method can allocate emission quotas to achieve economic efficiency of CO_2 emission reduction.

Finally, the optimal carbon emission quotas allocation for targeted industries should achieve CO_2 emission reduction target in a least-cost way. This study finds that the optimal allocation of carbon emission quotas in Thailand ETS can be achieved by equi-marginal method, the shares of the computed optimal initial carbon emission quotas for petrochemicals, cement, iron and steel, electricity, and aviation industries are 10.4133%, 10.9711%, 0.7111%, 73.5798% and 4.3247%, respectively. The total economic cost of all industries in Thailand ETS approximately 10.78% can be saved by implementing the optimal emission quotas allocation.

The results of this study are that answer the question of how to design the emission quotas allocation mechanism of ETS on different industries to achieve economic efficiency. The main findings of this study are as follow:

(1) Most of the studies on carbon emission permits allocation are commonly based on grandfathering or fixed allocation during initial start-up phases of ETS, this approach can be easily implemented and is the most general principles. However, this study focuses on unique point, the difference of EIERs between industries in Thailand ETS. The allowance allocation of ETS for participant industries may significantly affect environment and economy in Thailand. Thus, applying the equi-marginal

principle to explore CO_2 emission quota allocation among industries according to their EIERs for the sake of minimizing the economic cost of emission allocation.

(2) This study focuses on total economic cost and allocation method for carbon emission quotas allocation of targeted industries, for the sake of better choice of allowance allocation mechanism among industries in Thailand ETS.

5.2 Policy Implications

Based on the main findings from this study, several policy recommendations for Thailand ETS authority and the targeted participating sectors were obtained.

(1) The Thailand ETS regulator should adopt both the fairness and efficiency principles to optimal allocating carbon emission quotas for participant industries in Thailand ETS. Our findings imply that the Thailand ETS policies designed to allocate CO_2 emission quotas should be considered not only the historical GHG emissions percentage on the different industries but also considered the change in the economic cost per additional unit of CO_2 emission reduction. Therefore, this study indicated that the equi-marginal method to achieve the economic efficiency of emission reduction and the efficiency of allocation method, which obtain the optimal allocation of carbon emission quotas.

(2) Considering the electricity industry is the highest economic impact (according to the results in Section 4.3), we therefore suggest that the Thailand ETS authority should be allocate the total emission quotas for electricity greater than their proportion based on historical CO_2 emissions percentage as a reference base year, the largest carbon emission quotas in Thailand ETS market. Whereas the quota allowances for other industries are allocated in lower than their proportion. This finding relevant encourage to achieve the objectives of Thailand’s Climate Change Master Plan 2015 – 2050, Thailand is able to continue its economic, social, and environmental developments in accordance with sufficiency economy philosophy and to reduce greenhouse gas emissions by 2050, without impeding the country’s gross domestic product (GDP) or reducing its growth of developmental capability and competitiveness.

(3) The carbon emission quotas allocation could meaningfully influence each participant industries cost. Which suggest that Thailand ETS authority and the five targeted participating sectors need to aware the strength of direct and indirect economic cost within industries. Moreover, the participant industries required the internal cost for the reduction of CO_2 emission, and GHG abatement cost curve such as improvement of building, promoting low-energy vehicles, energy management and energy conservation in industrial processes and equipment e.g. refrigerating and air conditioning systems, utility system, electrical and lighting system, etc. The GHG abatement cost is also important, can significantly impact on ETS market.

5.3 Implications for Future Study

This study considered the comparative of two allocation methods for carbon emission quotas in Thailand ETS, for the sake of a reasonable emission quota allocation to ensuring the minimizing the economic cost of allocation. Nonetheless, there are opportunities for further study:

(1) There is possible to study the macroeconomic effect on carbon emission quotas allocation in Thailand ETS, the result of ETS will directly to economic affects e.g. real GDP, employment, investment, consumption, import, export, sector's outputs, etc. The macroeconomic impact study can be using Dynamic Computable General Equilibrium (CGE) model, it is important to support ETS policy makers to decision a cap setting on Thailand ETS.

(2) Greenhouse gas abatement cost curves is an interesting issue to explore further, to provide a fact base on GHGs emissions reduction cost and investment opportunities needs. It is meaningful management insights for businesses and ETS policy makers to set up appropriate abatement targets into effective emission quotas allocation to different sectors in Thailand ETS.

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APPENDIX

APPENDIX I

The Definition of Input-Output Table Code

Code	Sector	Description
001	Paddy	This sector covers the combined the production of both glutinous and no glutinous paddy. The by-product is straw.
002	Maize	This sector covers the combined production of fresh, dried and young maize including the by-products.
003	Other cereals	Production in this sector combines sorghum and barley including the by-products.
004	Cassava	The only product included in this sector is fresh cassava roots.
005	Other root crops	These include potato, sweet potato, taro root and other root-crops that are not mentioned in the other sectors.
006	Beans and nuts	This sector covers beans and nuts of all kinds such as mung bean, castor seed, kidney bean, red bean, sesame and ground nut.
007	Vegetable	Vegetables such as chili, ginger, Chinese radish, onion, shallot, garlic, cabbage, tomato and other vegetables not mentioned elsewhere are included in this sector.
008	Fruits	This sector includes the production of oranges, grapes, durians, rambutans, mangoes, pineapples, water melons, bananas, mangosteens, pomeloes, longens, jack fruits, lychees and other fruits not mentioned elsewhere.
009	Sugar cane	This sector refers to sugar cane consumed by households and for industrial purposes.
010	Coconut	Fresh coconut is the main product of this sector. Coconut leaf, coconut fiber, copra and coconut shells are the by-products.
011	Oil palm	Production in this sector contains oil palm and palm lily including their by-products.
012	Kenaf and jute	This sector covers the production of kenaf, jute and ramie.
013	Other crops for textile and matting	This sector includes fiber and seed of kapok and other fiber crops.
014	Tobacco	Fresh tobacco leaves and seeds are the two main agricultural products of this sector. Production is classified into Virginia Barley, Turkish and Native varieties.
015	Coffee and tea	This sector covers the production of all fresh coffee beans, tea leaf and cocoa.

Code	Sector	Description
016	Rubber	Latex from the rubber tree is the main product of this sector.
017	Other agricultural product	This sector covers flowers and seed of all kinds, including sunflower seeds, ornamental plants, horse tamarind and mint.
018	Cattle and buffalo	This sector covers the production of cattle and buffalo for slaughter, export and breeding. Fresh milk for dairying also contributes to this sector.
019	Swine	The only product included in this sector is swine.
020	Other livestock	Goat, sheep, horse, rabbit, crocodile, elephant and others are under this sector.
021	Poultry	This sector covers the production of chickens, ducks and geese.
022	Poultry products	The product covered by this sector is egg derived from raising fowl.
023	Silk worm	This sector includes the products of silk-worm and silk cocoons.
024	Agricultural services	This sector covers the plough services using both animals and tractors.
025	Logging	This sector includes logs of all kinds such as teak, yang, etc.
026	Charcoal and fire-wood	This sector covers the production of charcoal and firewood.
027	Other forest products	Products of this sector are bamboo, bamboo shoot, rattan and other forest products.
028	Ocean and coastal fishing	Covered in this sector are ocean fishing, coastal fishing and coastal fish-cultivation.
029	Inland fishing	This sector covers the activities of both inland fish catching and cultivation.
030	Coal and lignite	This sector includes establishments primarily engaged in mining coal and lignite.
031	Petroleum and natural gas	This sector covers the exploration activities for crude petroleum and natural gas, the drilling, completing and equipping of wells carried out on an own-account basis, and the operation of oil and natural gas wells.
032	Iron ore	This sector includes activities primarily involving the extraction and dressing of iron ore.
033	Tin ore	Activities involving extracting and dressing of tin ore is listed under this sector.
034	Tungsten ore	This sector include activities involved in extraction and the preparation of tungsten ore.
035	Other non-ferrous metals	This sector includes activities involved in extraction and dressing non-ferrous ore, such as antimony, chromite, columbite, copper, manganese, monazite, tantalite, zenotize, zinc, zircon and lead ore.

Code	Sector	Description
036	Fluorite	This sector covers the activities of exploration and extraction of fluorite.
037	Chemical fertilizers	Covered in this sector are activities related to the mining or other extraction of minerals such as fluorite, phosphate and nitrate mineral.
038	Salt	Covered in this sector are activities related to extraction of rock salt and the production of salt from sea water.
039	Limestone	This sector primarily covers the activity involved in the extraction of limestone.
040	Stone quarrying	This sector covers the activities of stone quarrying, clay extraction, gravel and sand pit operation, clay pit operation, and marble mining.
041	Other mining and quarrying	Excluding stone quarrying, this sector covers activities of mining and other quarrying productions such as asbestos, calcite, diatomite, dolomite, feldspar, gypsum, marl quartz, silica sand and jewelry stone.
042	Slaughtering	This sector covers the activity of slaughter-houses and products such as fresh meat, pork, chicken and duck. Also included are hides of cattle and buffalo, feathers of chicken and duck, buffalo horns and other by-products of cattle, buffalo, swine, chicken and duck.
043	Canning and preserving of meat	This sector covers the activity of canning and preserving meat, and the preparation of ham and sausage.
044	Dairy products	This sector covers pasteurized milk, condensed milk, cream, butter, cheese, margarine and ice cream.
045	Canning and preservation of fruit and vegetables	This sector covers dried and frozen fruits, canned and bottled fruits and vegetables, fruit and vegetable juice, jam, jellies and others.
046	Canning and preservation of fish and other sea foods	This sector covers frozen fish, preserved fish, salted and dried fish.
047	Coconut and palm oil	This sector covers coconut oil, palm oil, coconut cake and palm cake.
048	Animal oil, animal fat, vegetable oil and by-products	The products are lard, animal fat, soy-been oil, cotton-seed oil, kapok-seed oil, sunflower-seed oil, rice-bran oil, other vegetable oil, and the by-products.
049	Rice milling	This sector covers production of husked-cleaned-polished rice, parboiled rice, broken rice, rice bran and rice husk.
050	Tapioca milling	This sector covers milled products of cassava of all kinds such as tapioca flour, tapioca chips and tapioca

Code	Sector	Description
		pellets.
051	Grinding of maize	This sector covers maize milling activities such as the grinding corn, corn cob and other maize products.
052	Flour and other grain milling	This sector covers the activity of flour and other grain milling.
053	Bakery products	This sector covers all bakery products such as bread, cake, pies, and crackers.
054	Noodles and similar products	Covers in this sector are noodles of all kinds such as yellow noodles, white noodles made from rice flours, spaghetti, macaroni, etc. Instant noodles are also included here.
055	Sugar	This sector covers refined sugar made from sugar-cane and coconut trees as well as the by-products of sugar such as syrup, molasses and bagasse.
056	Confectionery	Candies, chocolate, chewing gum and other confectioneries are covered by this sector.
057	Ice	Ice is the sole product of this sector.
058	Monosodium glutamate	Monosodium glutamate is covered in this sector.
059	Coffee and tea	This sector covers the activities involved in the processing of coffee and tea. The productions covered by this sector are coffee and tea powers, instant coffee and tea as well as roasted coffee beans and tea leaves.
060	Other food products	This sector includes soy sauce, bean curd, fish sauce, vinegar, salted and fermented eggs, spices, table salt, other sauces and other prepared food.
061	Animal feed	Covered in this sector are the products of all kind animal feeds such chicken feed, fish meal.
062	Distilling and spirits blending	This sector covers brandy, liqueurs and wine.
063	Breweries	Malt and beer are included in this sector.
064	Soft drinks and carbonated water	This sector covers soda water, carbonated fruit drinks, distilled water and the other soft drinks.
065	Tobacco processing	This sector covers the activities of tobacco-leaf processing. Only dried tobacco-leaf is included in this sector. There are four kinds of dried tobacco-leaf, i.e., Virginia, Burley, Turkish and Native.
066	Tobacco products	This sector consists of cigar, cigarettes, cut tobacco and chewing tobacco.
067	Spinning	This sector includes cotton, synthetic silk yarn, spun, short and long synthetic staple. Excluded from this sector are yarns from jute and kenaf.
068	Weaving	Covered in this sector are cotton fabrics, mixed-cotton fabrics, synthetic fabrics and silk fabrics. Jute and kenaf fabrics are not included here.

Code	Sector	Description
069	Textile bleaching, printing and finishing	This sector covers the activities of printing, bleaching and finishing textile.
070	Made-up textile goods	This sector covers all textile processed products not classified elsewhere. Products included are household textile furnishing materials, textile bags, canvas products, lace and lace products, textile-coated fabrics, felt and felt products and textile wadding material.
071	Knitting	Covered in this sector are knitted fabrics and products from knitted fabrics. Knitting products made directly from yarn such as stocking are also included.
072	Wearing apparel	This sector covers the products of wearing apparel and allied clothing produced in factory, except woven products such as handkerchiefs, neckties, shawls and veils Excluded are all kind of wearing apparel made by tailors.
073	Carpets and rugs	This sector covers only the products of carpets and rugs made from textile materials. Carpets and rugs from straw or material other than textile are not included.
074	Jute mill products	Covered in this sector are products made from kenaf and jute. Other products included are yarn and fabrics of kenaf and jute except for those used in gunny bags. Fishing nets made from materials of all kinds are included in this sector.
075	Tanneries and leather finishing	The tanning and finishing of animal leather and skin are included in this sector. Excluded are all kinds of artificial leathers.
076	Leather products	Leather and artificial leather products are covered in this sector.
077	Footwear, except of rubber	This sector covers footwear made of leather, fabrics and other materials. It excludes the wholly made of wood or moulded rubber or plastic.
078	Saw mills	This sector covers sawn timber and other wooden construction materials such as plywood and chip board.
079	wood and cork products	Except for furniture and fixtures, this sector covers products made from wood, rattan and bamboo such as wooden boxes and containers. Also included are handicraft utensils, articles and parts of equipment which can be commonly installed in different kinds of equipments.
080	Wooden furniture and fixtures	This sector covers all kinds of furniture and fixtures except those made of metal.

Code	Sector	Description
081	Pulp, paper and paperboard	This sector covers pulp, paper and paperboard.
082	Paper and paperboard products	This sector include all kinds of paper and paperboard products such as paper boxes, book covers, writing-pads, envelopes, labels, paper bags and sanitary paper. Publishing house production such as books magazines and newspapers are not included.
083	Printing and publishing	This sector covers printing activities by one or more of the common processes such as the use of the letter-press, lithographing, offset printing and bookbinding. Publishing of newspapers, periodicals, books and maps are also included.
084	Basic industrial chemicals	This sector covers the manufacturing of basic industrial chemicals such as hydrogen, oxygen, nitrogen, chlorine, sulfur and other chemical elements; inorganic acids and other oxygen compounds of metalloids such as hydrochloric acid, sulfuric acid, nitric acid and carbon dioxide; inorganic bases and metallic oxides such as ammonia and caustic soda; salts of inorganic acids such as aluminum sulfate, potassium nitrate, soda ash, sodium silicate and calcium hypochloride; carbides; and organic chemicals such as methyl alcohol, polyhydric alcohols, esters of polyhydric alcohols, acetic acid and aldehydes.
085	Fertilizer and pesticides	The products of this are urea, ammonium sulfate, phosphate, chemical fertilizer, organic fertilizer, pesticides and insecticides.
086	Petrochemical products	This sector covers the activities involved in the processing of petrochemical. The productions covered by this sector are upstream production such as Ethylene, Propylene; intermediate production such as Vinyl chloride monomer, Styrene monomer and downstream production such as Polyvinyl chloride, Polyethylene, etc.
087	Paints	This sector covers the manufacture of paints, varnishes, stains and shellac, lacquers, enamels and japans. Also included are the manufacture of allied products such as composite thinners, paint removers, paint brush cleaners, putty and other coating and filling material. Dyes, organic and inorganic pigments are not included.
088	Drugs and medicines	This sector includes the production of drugs and medicines in all forms such as tablets, capsules, powder, syrup and liquids for injection. Traditional medicines such as herbs are also included.

Code	Sector	Description
089	Soap and cleaning preparations	The products included in this sector are soap, detergent, shampoo, glycerine and toilet preparation.
090	Cosmetic	This sector includes the production of perfumes, cosmetic, hair cream, toothpaste, talcum powder and deodorant.
091	Matches	This sector covers matches of all kinds.
092	Other chemical products	Included in this sector are the manufacture of chemical products such as furniture and metal polishes, leather polishes, waxes, adhesive and glues, candles, inks, carbon black and essential oil. Other products also included tanning and dyeing material such as natural indigo, vegetable dye, tanning agents and inorganic pigments. Wood chemicals such as gums and incense products such as joss sticks are also covered.
093	Petroleum refineries	This sector covers oil-processing refineries. The products in this sector comprise of gasoline, jet oil, LPG, asphalt, paraffin, sulfur, kerosene, diesel and fuel oil.
094	Other petroleum products	This sector covers refined oil, refined grease and lubricating oil
095	Rubber sheet and block rubber	This sector covers rubber sheets, block rubber, crepe rubber and other processed rubber.
096	Types and tubes	This sector covers all types and tubes such as those for passenger car, truck and bus, tractor, motorcycle and bicycle.
097	Other rubber products	This sector covers the manufacture of rubber products not classified elsewhere such as rubber raincoats, rubber gloves, rubber bags, rubber mats, rubber toys, rubber bands, rubber hose and tubes, rubber bottles and rubber sponges.
098	Plastic ware	This sector covers the moulding, extruding and fabricating of plastic articles such as plastic household articles, plastic containers and cups, plastic mats, and laminated sheets. Also included are plastic components for insulation, plastic furniture, and plastic industrial supplies.
099	Ceramic and earthen ware	The sector covers pottery, ceramic and earthenware for industrial and construction use. Sanitary supplies are also included.
100	Glass and glass products	This sector consists of window flat glass, bottles, drinking glasses, lamp chimneys and others.
101	Structural clay products	This sector covers bricks, tiles pipes, refractory bricks and other similarly structural clay products.
102	Cement	This sector consists of Portland cement, white cement and lime.

Code	Sector	Description
103	Concrete and cement products	This sector covers the manufacture of concrete products such as blocks, posts and piles, precast elements for prefabricates construction materials, other reinforced and pre-stressed concrete products as well as Buddha images and spirit houses.
104	Other non-metallic products	Included in this sector are the manufacture of gypsum plaster products, wood-wool board (cellocrete) and other asbestos product. Cut stone products which were not produced in conjunction with quarrying and all other non-metallic mineral products not classified elsewhere are also included.
105	Iron and steel	The sector covers pig iron, ingot, ferro-silicon, ferro-manganese and pig iron’s by-products.
106	Secondary steel products	The products of this sector are galvanized sheet, tin plate, angle bar and rod wire, tube and pipe. Steel forging, steel casting, polished steel are also included.
107	Non-ferrous metal	This sector covers the activities relating to the manufacture of primary non-ferrous metal products consisting of primary and secondary smelting, alloying, refining, rolling and drawing, founding and casting.
108	Cutlery and hand tools	This sector covers the manufacture of table, kitchen and other cutlery, hand and edge tools such as axes, sickles, shovels, rakes, hammers, screw drivers, files and handsaws and other agricultural and garden tools. Plumbers’, masons’, mechanics’ and machinists’ precision hand tools, hinges, locks key sets, builders’ hardware and marine luggage and vehicles hardware are also included.
109	Metal furniture and fixtures	This sector covers the manufacture and alteration of furniture and fixtures consisting primary of metal for household, office, public building, transport equipment, professional and restaurant uses.
110	Structure metal products	This sector covers the manufacture of steel or other metal structure components such as bridges, tanks, building structure, doors and screens, window frames and sashes, shutter, staircases, wrought iron gates. Other architectural metalwork such as metal components for ventilating and air-conditioning systems as well as steam and water-tanks are also included.
111	Other fabricated metal products	This sector covers the manufacture of fabricated metal products such as metal cans from tinplate, enameled sheet metal, metal conveyances, metal shipping containers, metal stamping, fabricates wire

Code	Sector	Description
		and wire products from purchased wire rods (excluding insulated wire and cable). Sanitary ware, plumbers' brass good, pipe fittings, enameling, lacquering, galvanizing, electroplating and polishing metal products and a variety of metal products not classified elsewhere are also included. In addition, the sector covers common machinery part such as bearing an spring, except specialized parts for motor vehicles, aircraft and ships which belong to their respective machinery sectors.
112	Engines and turbines	This sector covers the assembling of stream engines, other engines and turbines. Also included are the parts and repair of engines and turbines.
113	Agricultural machinery and equipment	This sector covers the assembling of cultivating machines and equipment, sawing and planting machines, harvesting machines and equipment. Parts and repair of agricultural machines and equipment are also part of this sector.
114	Wood and metal working machines	This sector covers the activities relating to the assembling of wood and metal working machines such as sawing machines, and the parts and repairing of such machines.
115	Special industrial machinery	This sector covers all kinds of industrial machines except those used for wood and metalworking, agricultural machines as well as electrical machines. Machinery included in the sector is for example, construction and mining machines, food and chemical machines, leather and textile machines, etc. Also included in this sector are pneumatic tools, carrying and loading equipment such as cranes, forklifts and loading trucks, etc. Additionally, parts of such machinery and their repair are also included.
116	Office and household machinery and appliances	This sector covers the assembling of office and household machinery and appliances such as air conditioners, refrigerator, freezers, water cooler, sewing machines, typewriters, electric calculators and all parts. The repair parts are not covered in this sector.
117	Electrical industrial machinery and appliances	This sector covers the products of electrical industrial machinery and appliances such as generators, transformer, rectifiers, motors, electrical hand tools, electrical motors, electrical welding machines and other electrical machines. Parts for these machines are also are also included.
118	Radio, television and communication	This sector covers the assembly of radios, television sets, tape and cassette recorders, stereo components,

Code	Sector	Description
	equipment and apparatus	telephone and other communication equipment. Also included are their parts but repairing is excluded.
119	Household electrical appliances	This sector covers the production of household electrical appliances such as electric stoves, electric iron, electric fans, rice cooker, toasters, food mixers and all their parts.
120	Insulated wire and cable	This sector covers the production of insulates wire and cable.
121	Electric accumulators and batteries	This sector covers the production of batteries and dry cells Parts such as lead plates are also included.
122	Other electrical apparatus and supplies	This sector covers electrical apparatus and supplies not classified elsewhere, such as electric bulbs, and related light sources. Other products included are conductors, fuses, connectors, etc.
123	Ship building and repairing	Covered in this sector are the building and repairing of ship, boat and other water transport vessels. Parts for these vessels are also included in the sector.
124	Railroad equipment	This sector covers the production of railroad passenger cars and wagons. The parts and repairs of such equipment are also included in the sector.
125	Motor vehicles	This sector covers the production and assembly of motor vehicles. The products included are passenger cars, trucks, vans, pick-up, buses and the classis and parts of such vehicles.
126	Motor vehicles	The products of this sector are motorcycles, tricycles, bicycles, carriages and parts for such products.
127	Repair of motor vehicles	This sector covers automobile and motorcycle repair of all kinds.
128	Aircraft	This sector covers only aircraft repairing.
129	Scientific equipment	The sector covers measuring equipment, medical equipment and the parts and repairs of such equipment.
130	Photographic and optical goods	This sector include optical goods, spectacles, telescopes, astronomical instruments, microscopes, projectors, cameras, photo copying apparatus and parts for these products.
131	Watches and clocks	This sector covers the production and the assembly of clocks and watches.
132	Jewelry and related articles	This sector covers activities primary related to the manufacturing of jewelry using precious metals, precious and semi-precious stones and pearls, silverware and plotted ware using silver, gold and other precious metal plating. The cutting and polishing of precious stones and the making of coins and medals from precious metal are also included.

Code	Sector	Description
133	Recreational and athletic equipment	The products in this sector include musical instruments, music recording, footballs, golf balls, badminton rackets, boxing gloves and other recreational and athletic equipment.
134	Other manufactured goods	This sector covers the products that have been excluded from the manufacturing sectors by code 042 to 133. The main products of this sector are stationary, toys, umbrella, zippers, buttons, fasteners, etc.
135	Electricity	This sector covers the generation, transmission and distribution of electric for sale to household, industrial, commercial and public users. Electricity generation plants owned by manufacturing enterprises for their own use are also included.
136	Pipe line and gas distribution	This sector covers gas distribution such as LPG, ethane, propane, natural gasoline (NGL).
137	Water work and supply	This sector covers the activities related to the purification and distribution of water to household, industrial, commercial and public users. The operation of irrigation system is not included in this sector.
138	Residential building construction	This sector covers the construction of new building for residential purposes such as homes, sop houses, apartments and dormitories. The activities of extending, repairing, painting and decorating buildings as well as the installation of electricity and air conditioning systems are also included. Excluded from this section are the costs of acquiring land.
139	Non-residential building construction	This sector covers the construction of new non-residential building such as business building, factories, hotels, school, hospitals, and warehouse as well as related activities of extension and repair. Excluded are the constructions of railway station, power station or communication plants.
140	Public works for agriculture and forestry	This sector covers the construction and extension of irrigation works for agriculture and forestry. Only new construction is included.
141	Non-agriculture public works	This sector covers the construction and repair of highway, streets, roads, bridges, airports, water supplies and sewage systems.
142	Construction of electric plants	This sector covers the construction and repair of electricity generating plants and transmission systems.
143	Construction of communication	This sector covers the construction and repair of broadcasting and communication systems such as

Code	Sector	Description
	facilities	radio station, town telephone installation and other facilities.
144	Other construction	This sector covers the construction work not classified elsewhere such as the construction of public parks, parking lots, golf courses, tennis courts, swimming pools and athletic fields of all kinds.
145	Wholesale trade	This sector includes establishments for the re-sale of new and used goods to retail, industrial, commercial, institutional and professional outlets, as well as for other wholesale uses. Agents engaged in buying or selling merchandise are also covered in the sector. The principal type of business included are wholesale merchants engaged in own-account buying and selling, industrial distributors, exporters and co-operative buying associations and sales offices maintained by mining or manufacturing enterprises for the purpose of marketing their products. Also included are co-operative associations engaged in the marketing of farm produce, scrap metal and waste dealers, junk yards, wholesalers who sort and grade goods in large lots wholesale packers, bottling companies except those engaged in packing or bottling in airtight containers.
146	Retail trade	This sector included establishments engaged in the sale to the general public of new and used goods for personal or household consumption. Retailing establishments include shops, department stores, stalls, gasoline service stations, retail motor vehicle dealers, peddlers, consumer co-operatives, and auction houses. Included also are own-account retailers who act as agents, buying and selling on consignment or on a commission basis. Establishments engaged in selling displayed merchandise such as typewriters, stationary and petrol to the general public are classified in this group though these goods may not be for personal or household uses.
147	Restaurants and drinking places	The sector includes establishments engaged in selling prepared food or drink for immediate consumption such as nightclubs, restaurants, bard, coffee shops, etc. Also included are canteens and eating facilities in plants and offices. Restaurants operated by hotels and massage parlors for the general public, food peddlers and noodle stands are also included.
148	Hotels and places of loading	This sector includes establishments engaged in the provision for fee of lodging and camping facilities

Code	Sector	Description
		whether open to the general public or restricted to members of a particular organization. Related restaurant facilities operated for the purpose of serving the establishment's customers are also included.
149	Railways	This sector covers the service related to the transportation of both passengers and cargo. Also included are dining car services. Note that the repair of railway equipment is not covered in this sector.
150	Road passenger transport	This sector covers only the transport of passengers by taxicabs, buses, inter-city buses and other vehicles such as tricycles. Private vehicles for personal transportation are excluded.
151	Road freight transport	This sector covers local and long distance trucking. Also included are such services for one's own business purposes.
152	Land transport support service	This sector includes all land transport support services such as the operation of parking lots, toll roads rental of automobiles and self-driven trucks.
153	Ocean transport	This sector covers the ocean transport of both passengers and freight.
154	Coastal and inland water transport	This sector refers to the operation of freight and passenger vessels along various parts of the coast of Thailand. Those operated on inland waterways, river ferries and tugboats are included.
155	Water transport services	Included in this sector are the provision of supporting services for water transport of all kinds such as the maintenance and operation of harbors, docks, lighthouses and other navigation aids, loading and unloading services, the salvaging of vessels, ship leasing and rental. Included in this sector are the activities of the Port Authority of Thailand.
156	Air transport	The transportation of passengers and freight by air by regular services or by charter are covered in this sector. The operation of airports, landing fields and navigational facilities such as flight control centers, radar stations and the rental of aircraft are also included in the sector.
157	Other services	This sector covers the activity of establishments engaged in providing travel information and arranging tours and transportation for passengers. The activities of establishments engaged in cargo transportation are also covered.
158	Storage and warehousing	This sector covers the operation of storage facilities and warehouse. Silo services for drying maize are

Code	Sector	Description
		also included.
159	Post and telecommunication	This sector covers the services of central and provincial offices of the Telephone Organization of Thailand. Construction and radio-communication activities of the Post and Telegraph Department are not included.
160	Banking services	This sector covers all activities of monetary and financial institutions. Central bank, commercial banks, development banks, saving bank, rural banks, pawnshops, credit cooperatives and foreign exchange dealers make up this sector.
161	Life insurance services	Life insurance is defined as the activities of life insurance institutions and related services.
162	Other insurance services	This sector covers all insurance other than life such as fire, accident, marine and health insurance.
163	Real estate	This sector covers the activities of real estate agents and brokers
164	Business services	The sector includes service such as accounting, auditing and book-keeping services, data processing and tabulating services, engineering, architectural and technical services, parliament and the judicial authorities.
165	Public administration	The sector covers the central, provincial and local government, as well as the royal household, parliament and the judicial authorities.
166	Sanitary and similar services	This sector covers the activities related to sanitary and similar services such as garbage and sewage disposal, the operation of drainage systems and the purification of water for consumption as well as the cleaning services.
167	Education	This sector covers all public and education institution at all levels such as kindergartens, primary schools, secondary schools, colleges and universities. Also included are vocational schools and others providing specialized education such as language and painting schools. Research institute, hospitals belonging to universities, as well as education provided neither by government nor household are not included.
168	Research	This sector includes institutions primarily engaged in basic and general research in the biological, physical and social sciences. Since information on private research institutes in Thailand is not available, the only researches available are accomplished by government offices, universities and public enterprises, hence they are included here.

Code	Sector	Description
169	Hospital	Covered in this sector are medical, surgical, dental and other health services. This includes hospitals, sanitariums, nursing homes and similar institution, maternity and child welfare clinics, consulting offices of physicians, surgeons and other medical practitioners such as dentists, the services of midwives and nurses in private practice ambulance services. The sector extends to medical and dental laboratories that provide testing, diagnostic and other service to the medical and dental professions. Activities primary relating to the manufacture of dental supplies and artificial teeth to order are also included.
170	Business and labor associations	This sector includes private business institution such as the Board of Trade of Thailand, the Thai Chamber of Commerce, The Association of Thai industries and professional organizations such as the Engineering Institute of Thailand, labor unions and labor organization.
171	Other community service	This sector includes institution engaged in providing social welfare services such as the Red Cross Society and other organization for the collection and allocation of charitable contribution such as children and societies, dry nurseries, orphanages, home for destitute adults, homes for handicapped person, home for aged, family welfare society and other charitable organization. This section was classified broadly into three types of organizations, namely, Red Cross Society, other charitable organizations and religious organizations.
172	Movie theatres	This sector covers the activities relating to the production of motion pictures for showing. They also include both still and slide films. Other related services such as film developing, printing, film editing, titling, copying and distributing of both local and foreign films are also included.
173	Movie theatres	All theatres and movie houses are covered in this sector.
174	Radio, television and related services	Included in this sector are radio and television stations primarily engaged in the production and dissemination of audiovisual programs for the public. The activities of television and radio relay stations are also included in this sector.
175	Libraries and museums	This sector covers the operation of libraries, information centers, archeological and others museums, art galleries, botanical and zoological

Code	Sector	Description
		gardens and similar institutions.
176	Amusement and recreation	This sector covers the activities of theatres providing theatrical presentation such as classical drama, dance and concerts, entertainment services such as those provided by bands and orchestras and musical recording. This sector also includes the services related to theatrical presentation such as those provided by booking agencies for plays. Self-employed artists and instructors such as actors, dancers, musicians, singer and other entertainers and producers for radio and television programs, motion picture, play and other presentations, composers and song writers, authors, painters and operators of dance halls. Additionally, bowling alleys, billiard and pool rooms, race tracks, boxing stadiums, football fields, sports clubs, gymnasiums, tennis courts, golf courses, sport promoters, operators, of amusement parks and renters of pleasure boats, motorcycles, golf carts, saddle horses and similar recreation goods add into this sector.
177	Repair not classified elsewhere	This sector included establishments specialized in the repair of household appliances, equipment and furnishing, motor cars and other consumers goods which are not classified elsewhere. Also included in this sector are establishments specialized in the installation of household appliances such as stoves and ranges, refrigerators, air-conditioning apparatus and television sets.
178	Personal service	This sector included establishments primarily engaged in washing, ironing, dry cleaning, pressing and dyeing apparel, house furnishing or household fabrics. The repair of clothing, bedspreads, blanket, curtains and other personal and household textiles are also included in this sector. This sector also included the services of maids, cooks, gardeners, caretakers and other maintenance workers for household, whether provided by individuals who are employed by these households or by business units primarily engaged in furnishing these services. Establishments engaged in rendering personal care and services not classified elsewhere such as barber hairdressing and beauty shop, photographic studios, Turkish baths establishments, massage parlors and crematories are accounted here.

Code	Sector	Description
179	Other service not classified elsewhere	This sector included all services that are not covered by other sectors.
180	Unclassified	This sector includes mainly activities not classified elsewhere.
190	Total intermediate transactions	This is the sum of sectors 001 to 180.
201	Wages and salaries	This sector covers compensation by employers to employees both in cash and in kind. Employees are classified as long-term workers, temporary workers, temporary workers, executives and hired laborers in the agricultural sector, but not family workers.
202	Operating surplus	The operating surplus is defined as the total value added including business income tax, minus wages and salaries, depreciation and indirect taxes, less the subsidies.
203	Depreciation	Depreciation consists of capital consumption allowances for all fixed assets. The imputation of depreciation of government buildings is described in the public administration sector and that of self-occupied dwellings is in real estate sector. The depreciation on fixed assets for leasing such as computers is shown in the sector of owner of fixed assets for leasing such as computers is show in the sector of owner of fixed assets.
204	Indirect taxes less subsidies	Indirect taxes cover the domestic commodity sales tax, export duty, licensing fees, service tax of hotels, restaurant and the like, duty stamps and special commodity tax such as those on automobiles, electrical equipment, alcoholic drinks, cigarettes, petroleum products, etc.
209	Total value added	This is sum of all the primary inputs from 201 to 204.
210	Control total	This is sum of total intermediate transactions and value added.
301	Private consumption expenditures	Private consumption expenditures are the current expenditures on goods and services by households and private non-profit organizations. The expenditure also cover the expenditures of Thai nationals abroad as tourists and the expenditures of the family of a foreigner who is working for a private company or a non-profit organization in Thailand.
302	Government consumption expenditure	Government consumption expenditures cover all current expenditures of government for goods and services, including those for the police and military forces. Expenditures of Royal household are also included. However, consumption expenditures of public enterprises which are profit-making are not

Code	Sector	Description
		included.
303	Gross domestic fixed capital formation	Gross domestic fixed capital formation includes fixed assets such as land, buildings, machinery and equipment belonging to households, government and private enterprise except those for military use. Public infrastructure such as roads, dams and power stations are also included. However, installation costs of equipment and machinery are not covered.
304	Increase in stock	Stocks or inventories comprise of the followings: finished products stored in producers' factories or warehouses, unused raw materials purchased by producers, semi-processed products and products on processing lines and marketable stocks held by wholesalers and retailers. Stocks kept by households are not included.
305	Export	In the input-output table at purchasers' prices, exports were valued at f.o.b. prices. As for producers' prices, exports were valued by subtracting trade margins and transport costs from f.o.b. process.
306	Special exports	Special exports cover non-merchandised goods and services which are not included in the official export statistics. Item which are included here are freight and insurance related to export, expenditures of foreign tourists in Thailand and related transportation cost, expenditures of foreign government organization, international organizations and families of diplomats, expenditures of foreign military bases, other service charges which are paid by foreigners and estimated smuggling.
309	Total final demand	This is the sum of codes 301 to 306.
310	Total demand	This is the sum of codes 190 and 309.
401	Imports	Imports were valued at c.i.f. process plus tariff. However, for valuation at domestic producers' prices, the transport costs and insurance paid by the Thai importers were subtracted in order to avoid double counting. A special treatment was used here. The redundant transport costs and insurance were regarded as special exports and are treated in the special export sector.
402	Import duty	Customs duty on imports is included under this code.
403	Import tax	The Import tax includes both import sales tax and municipal tax on imported.
404	Special imports	As in the case special exports, special imports are non-merchandised goods and services which are not covered in the official trade statistics, e.g. expenditures of Thai nationals abroad, expenditure of

Code	Sector	Description
		Thai government organizations and of the families of Thai diplomats outside Thailand and estimated smuggling into Thailand.
409	Total imports	This is the sum of codes 401 to 404.
501	Wholesale trade margin	Wholesale trade margin is margin of goods from factory towards retail trade.
502	Retail trade margin	Retail trade margin is margin of goods from retail towards household consumption.
503	Transport cost	The transport costs are the cost of transporting goods from factory to the consumers.
509	Total trade margin and transport costs	This is the sum of codes 501 to 503.
600	Control total	This is the sum of total intermediate transactions and final demands which indicates the output distribution of the table and is equal to codes 190 + 309 + 409 +509.
700	Total supply	The total supply is equal to codes 600 – 409 – 509.

APPENDIX II

Estimation of Fossil Fuels Consumption

1. The fuels consumption value ratio data from Thailand energy situation in 2010

Type of fossil fuels	Units	Fossil Fuels Consumption Value Ratio (%)[1/]				
		Petrochemical (S 86)	Cement (S 102)	Iron & Steel (S 106)	Electricity (S 135)	Aviation (S 156)
Coal and its products						
Anthracite	kg	0.00	0.00	0.00	1.02	0.00
Bituminous	kg	0.00	0.00	0.00	20.67	0.00
Sub-bituminous	kg	0.00	0.00	0.00	0.00	0.00
Lignite	kg	0.00	36.21	0.00	78.31	0.00
Coal coke	kg	0.00	0.12	0.00	0.00	0.00
Coal	kg	0.00	63.66	0.00	0.00	0.00
Total Coal and its products		0.00	100.00	0.00	100.00	0.00
Petroleum oil products						
Diesel	litre	0.16	16.75	1.01	15.89	0.00
Gasoline	litre	0.00	0.00	0.00	0.01	0.00
Fuel oil	litre	46.17	80.71	85.92	84.10	0.00
Kerosene	litre	0.24	0.00	0.15	0.00	0.00

Type of fossil fuels	Units	Fossil Fuels Consumption Value Ratio (%)[1/]				
		Petrochemical (S 86)	Cement (S 102)	Iron & Steel (S 106)	Electricity (S 135)	Aviation (S 156)
Liquefied Petroleum Gas (LPG)	litre	53.43	2.54	12.92	0.00	0.00
Jet kerosene	litre	0.00	0.00	0.00	0.00	100.00
Total Petroleum oil products		100.00	100.00	100.00	100.00	100.00

Source [1/] The fuels consumption value ratio data from Thailand energy situation in 2010 released by Bureau of Energy Regulation and Conservation, Department of Alternative Energy Development and Efficiency.

2. The fuels consumption value drawn from the input-output table of Thailand in 2010

The fossil fuels consumption data from input-output table of Thailand released in 2010 are shown in Baht value. The fuels consumption for each type is calculated by contribution the fuel consumption ratio from Thailand energy situation in 2010 into the fuel consumption value on I-O table.

Type of fossil fuels	Fossil Fuels Consumption Value (10^3 Baht)				
	Petrochemical (S 86)	**Cement (S 102)**	**Iron & Steel (S 106)**	**Electricity (S 135)**	**Aviation (S 156)**
Coal and its products					
Anthracite	0	0	0	325,273	0
Bituminous	0	0	0	6,575,501	0
Sub-bituminous	0	0	0	0	0
Lignite	0	2,993,507	0	24,907,531	0
Coal coke	0	10,322	0	0	0
Coal	0	5,262,966	0	0	0
Total Coal and its products [1/]	**0**	**8,266,795**	**0**	**31,808,305**	**0**
Petroleum oil products					
Diesel	32,025	1,014,559	30,793	419,120	0
Gasoline	0	0	0	0	0
Fuel oil	10,626,486	5,707,464	3,066,340	41,734,983	0
Kerosene	34,104	0	3,347	45,562	0
Liquefied Petroleum Gas (LPG)	29,631,018	432,509	1,111,045	15,122,083	0

Type of fossil fuels	Fossil Fuels Consumption Value (10^3 Baht)				
	Petrochemical (S 86)	**Cement (S 102)**	**Iron & Steel (S 106)**	**Electricity (S 135)**	**Aviation (S 156)**
Jet kerosene	0	0	0	0	63,782,840
Total Petroleum oil products [1/]	**40,323,632**	**7,154,531**	**4,211,526**	**57,321,749**	**63,782,840**
Natural gas					
Natural gas	1,616,917,238	53,032,286	31,111,524	12,756,572,571	328,190
Total Natural gas [1/]	**1,616,917,238**	**53,032,286**	**31,111,524**	**12,756,572,571**	**328,190**

Source [1/] The fuels consumption value data from I-O table 2010

3. The quantity of fossil fuels consumption

The quantity of fossil fuels consumption is computed from fossil fuels consumption value by converting the consumption value into the physical quantity unit. The conversion is based on the fuel prices reported in Thailand energy situation in 2010 and Energy balance of Thailand in 2010.

Type of fossil fuels	Unit	Fossil Fuels Price in 2010 (Baht/Unit)	Fossil Fuels Consumption				
			Petrochemical (S 86)	Cement (S 102)	Iron & Steel (S 106)	Electricity (S 135)	Aviation (S 156)
Coal and its products							
Anthracite	kg	4.187	0	0	0	77,686,482	0
Bituminous	kg	2.349	0	0	0	2,799,276,697	0
Sub-bituminous	kg	1.977	0	0	0	0	0
Lignite	kg	0.5697	0	5,254,531,780	0	43,720,433,101	0
Coal coke	kg	6.825	0	1,512,398	0	0	0
Coal	kg	3.36	0	1,566,358,967	0	0	0
Total Coal and its products			**0**	**6,822,403,145**	**0**	**46,597,396,280**	**0**
Petroleum oil products							
Diesel	litre	27.55	1,162,426	36,826,088	1,117,731	15,213,084	38,094
Gasoline	litre	36.1	0	0	0	0	0
Fuel oil	litre	23.59	450,465,696	241,944,199	129,984,736	1,769,181,145	0
Kerosene	litre	37.51	909,192	0	89,243	1,214,659	0

Type of fossil fuels	Unit	Fossil Fuels Price in 2010 (Baht/Unit)	Fossil Fuels Consumption				
			Petrochemical (S 86)	Cement (S 102)	Iron & Steel (S 106)	Electricity (S 135)	Aviation (S 156)
Liquefied Petroleum Gas (LPG)	litre	9.79	3,026,661,657	44,178,614	113,487,752	1,544,645,910	0
Jet kerosene	litre	37.51	0	0	0	0	1,700,394,308
Total Petroleum oil products			**3,479,198,971**	**322,948,900**	**244,679,461**	**3,330,254,799**	**1,700,394,308**
Natural gas							
Natural gas	scf	10.5	1,616,917,238	53,032,286	31,111,524	12,756,572,571	0
Total Natural gas			1,616,917,238	53,032,286	31,111,524	12,756,572,571	0

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